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Manganese Availability—Market Economy Countries

A Minerals Availability Program Appraisal

By Joseph S. Coffman and Cesar M. Palencia

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 8978

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UNITED STATES DEPARTMENT OF THE INTERIOR
William P. Clark, Secretary

BUREAU OF MINES
Robert C. Horton, Director

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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PREFACE

The purpose of the Bureau of Mines Minerals Availability Program (MAP) is to assess the worldwide availability of nonfuel minerals. The program identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits, and on mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availabilities.

This report is part of a continuing series of Minerals Availability Program reports that analyze the availability of minerals from domestic and foreign sources and the factors that affect availability. Analyses of other minerals are currently in progress. Questions about the Minerals Availability Program should be addressed to the Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., NW., Washington, DC 20241.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu	British thermal unit	m	meter
ft^3	cubic foot	mm	millimeter
kg	kilogram	μm	micrometer
kg/m^3	kilogram per cubic meter	pct	percent
km	kilometer	ton	metric ton unless otherwise noted
lb	pound		

MANGANESE AVAILABILITY—MARKET ECONOMY COUNTRIES

A Minerals Availability Program Appraisal

By Joseph S. Coffman[1] and Cesar M. Palencia[2]

ABSTRACT

To determine the availability of manganese for metallurgical purposes from selected world resources, the Bureau of Mines evaluated the potential production of contained manganese in concentrates based on the demonstrated resources of 23 foreign and 8 domestic mines and deposits in 9 market economy countries. All but 2 of the 23 foreign deposits are operating mines; none of the domestic deposits are in operation.

The demonstrated resources of the mines and deposits used in this study represent an in situ ore resource of approximately 2.2 billion tons,[3] containing 780 million tons of manganese with a total recoverable production potential of 514 million tons of contained manganese in concentrates. The analyses of mines and deposits in this study indicate that about 213 million tons of the contained manganese (41 pct) is potentially available at a January 1981 constant dollar long-run total cost of up to $1.50 per long ton unit (22.4 lb, or 10.15 kg contained Mn), approximately 428 million tons (83 pct) is potentially available at a cost of about $1.75 or less, and 491 million tons (95 pct) is available at less than $3.30. The remaining 23 million tons, which is potentially available at much higher costs (about $8 to $35 per unit), represents the U.S. deposits. On an annual basis, with a cost range of up to $1.75 per long ton unit, the availability from currently operating mines would last at least 80 years based on 1980 world production data. Total manganese production costs are estimated to comprise mining—8 pct, beneficiation—3 pct, transportation—26 pct, and smelting—63 pct.

[1] Metallurgist. [2] Mining engineer.
Minerals Availability Field Office, Bureau of Mines, Denver, CO.
[3] Unless otherwise noted, "tons" refer to metric tons.

INTRODUCTION

Manganese is a vital element in an industrial society; virtually all steels must contain some manganese to improve malleability. No other metal can be substituted for this purpose. Over 90 pct of all manganese produced is used in the ferrous and nonferrous metallurgical industries for improving metal strength and workability qualities. The remaining amount is used in the battery and chemical industries.

The United States is highly dependent on imports for its supply of manganese and has no resource that could economically offset an interruption of foreign supply. In 1981, the United States imported approximately 265,000 tons of manganese ores and concentrates and 620,000 tons of ferromanganese, which represented an apparent 99-pct import dependence (*17*, p. 96).[4]

The purpose of this report is to evaluate selected domestic and market economy country resources of manganese for metallurgical application. Individual mine and deposit evaluations were performed on the basis of tonnage, grade, and cost of production.

In 1982, about 11.6 million tons of manganese ore was produced in 21 market economy countries. Production in the nine countries used in this study accounted for more than 98 pct of this total. Since a high percentage of all manganese produced is used in the metallurgical industry, this study includes only resources suitable principally for metallurgical use.

In this study, final engineering and economic evaluations were performed on 31 mines and deposits. This includes eight U.S. deposits analyzed in a recent report on the availability of U.S. manganese (*10*). A total of 52 deposits were investigated; however, 21 were excluded from the final analysis because their demonstrated tonnages were negligible or the product was used in the battery and/or chemical industries. Deposits investigated but not included in the final analysis are shown in the appendix.

The procedure for conducting this study was to identify and define demonstrated manganese resources and the engineering and economic parameters that would affect production from these selected deposits. Capital investment and operating costs for the mining and beneficiation methods were estimated, and a cost analysis for each deposit was performed. Allowances were made for mine and mill recoveries of manganese from each deposit, and results are reported on the basis of U.S. dollars per long ton unit (22.4 lb or 10.15 kg) of recoverable manganese contained in the concentrates. Estimated production costs are in constant January 1981 dollars and include all required costs to deliver the material to existing ferromanganese smelting areas, according to assumed delivery patterns. The long-run operating costs were estimated to cover mining and processing of the entire demonstrated resource of each mine and deposit. Estimated ferromanganese smelting costs are presented to assess their relative effect on total production costs.

Total resources evaluated amount to about 2.2 billion tons of in situ material with about 779 million tons of contained manganese. From this, about 514 million tons of manganese (metal content) is recoverable after all mine and mill recoveries have been applied. This addresses greater than 98 pct of all known demonstrated resources at current mining grades. All resources are estimated as of January 1, 1980.

U.S. ferromanganese production has been declining in recent years. The current annual capacity available for production is 250,000 to 350,000 tons, much of which is shut down.

COMMODITY OVERVIEW

Manganese is the 12th most abundant element in the Earth's crust, and thus manganiferous occurrences are relatively widespread. It is a relatively low-value commodity of abundant supply and is used in larger quantities than other ferroalloy materials.

Manganese occurs in the form of numerous mineral assemblages of varying constituents or mixtures of one or more minerals. The most important economic minerals include bixbyite, braunite, cryptomelane, hausmannite, jacobsite, pyrolusite, rhodochrosite, romanechite (psilomelane), and wad. With the exception of rhodochrosite, which is a carbonate, all these minerals are oxides or mixed oxides and silicates.

The physical and chemical properties of manganese enhance its strategic value in that other elements can rarely substitute satisfactorily for the use of manganese on a cost-effective basis. No workable substitutes have been found for the metallurgical uses of manganese; only in chemical uses may substitutions be made. Manganese metal oxidizes readily and as metal by itself has no practical use.

In ancient times, oxides of manganese were used as colorizers and decolorizers for ceramics and glass; elemental manganese was first isolated in 1774. Manganese additions to steel began with experiments in 1839 which demonstrated that manganese increased the malleability of steel. Large-scale usage of manganese for steel alloying began in 1856 with the addition of spiegeleisen (a low-grade ferromanganese) to the bessemer steel process. In 1888, high-alloy, wear-resistant steels were developed. The invention of the wet galvanic electric cell led to the development of the dry cell battery in 1886, which currently represents one of the largest nonmetallurgical uses of manganese. Oxides of manganese combine easily with a wide range of organic and inorganic acids which are utilized in the chemical industry (*3*, pp. 653–654).

Nearly all manganese resources are located at relatively great distances from the major consuming centers in the United States, Europe, and Japan. A certain amount of manganese concentrate production is processed into ferroalloys or used in direct blast furnace application in countries where it is produced, although the majority is shipped to the major consuming centers.

International trade in manganese concentrate is restricted to a relatively small number of users, principal-

[4] Italicized numbers in parentheses refer to items in the list of references preceding the appendix.

ly consuming steel mills and intermediate ferromanganese producers. Some manganese producers have sales contracts with steel mills which may hold an equity investment in the mine itself. A relatively small amount of manganese concentrate production is sold on the spot market.

INDUSTRIAL APPLICATIONS

The metallurgical uses of manganese involve the application of raw ore in various forms and its use in the manufacture of manganese ferroalloys. The ores are utilized as a smelting aid in the blast furnace and in the manufacture of manganese ferroalloys; the ferroalloys are usually added to the ladle in steelmaking.

The use of manganese in the production or manufacture of steel begins with additions of manganiferous materials to the blast furnace charge as an enhancement to smelting. This can be in virtually any form or grade, such as ore, sinter, slag, scrap, manganiferous iron ore, etc. In some areas, iron ores are manganiferous to the extent that little or no additional manganese ore is needed in the process.

The principal value is in the manganese acting as a sulfur scavenger and as an enhancement to smelting in that it increases refractory lining life. A certain amount of the blast furnace manganese is passed on to the steel furnaces, where it reduces slag viscosity.

It is estimated that in terms of total manganese metal (content) consumed from all sources—that is, manganese ores and lower grade manganiferous iron ores—about 45 pct is used in the blast furnace (*9*, p. 29). It is estimated that about one-half of this is from manganese ores that contain less than 35 pct manganese. The remainder would be from low-grade manganiferous iron ores and ferruginous manganese ores that are not primarily mined for manganese.

The value of manganese as an alloying agent is its property for improving various qualities of iron and steel. It enhances the toughness, hardening properties under working conditions, hardness, and overall strength of steels. Virtually all steels contain certain amounts of manganese (0.5 to 1.5 pct.) The wear-resistant alloys (Hadfield steels) contain about 10 to 14 pct manganese.

PRODUCTION

ORE AND CONCENTRATES

Market economy country annual manganese ore and concentrate production in 1982 is estimated to be approximately 11.6 million tons. Production data for 1976–82 are shown in table 1.

The centrally planned economy countries historically produced approximately 45 pct of the world's manganese ore; however, these countries as a bloc have become net ore importers in recent years. It has been estimated that the U.S.S.R. requires much more manganese per unit of crude steel than does the United States, presumably because of lower grade ores, lower manganese recoveries, and the use of high-sulfur coke (*9*, p. 4).

The grades of the ores and concentrates shown in table 1 vary between considerable limits, and since data

Table 1.—Market economy country manganese ore and concentrate production, 1976–82
(Thousand tons)

Country[1]	Manganese, pct	1976	1977	1978	1979	1980	1981	1982[e]
Australia	37–53	2,154	1,389	1,241	1,723	2,019	1,448	1,132
Bolivia	28-54	12	9	1	11	1	1	–
Brazil	38-50	1,696	1,515	1,916	2,258	2,281	2,042	1,300
Chile	32-36	24	18	24	25	28	25	–
Egypt	28 +	4	4	–	–	–	–	24
Gabon	50-53	2,216	1,850	1,710	2,299	2,146	1,487	1,512
Ghana	30-50	312	292	316	272	252	225	132
Greece	48-50	8	10	7	5	5	5	5
India	10-54	1,834	1,865	1,619	1,755	1,645	1,526	1,466
Indonesia	47-56	10	6	5	6	5	3	4
Iran	33 +	40	40	30	20	–	–	–
Italy	30	4	9	10	10	9	9	9
Japan	24-28	142	126	104	89	80	87	82
Korea	23-40	1	1	1	–	–	–	–
Mexico	27 +	453	487	523	493	447	578	509
Morocco	50-53	117	114	126	136	132	110	94
Philippines	35-45	11	21	4	4	3	3	3
South Africa	30-48 +	5,451	5,047	4,345	5,182	5,694	5,038	5,215
Thailand	46-50	50	77	73	35	54	11	8
Turkey	27-46	17	19	68	42	42	15	5
United States[2]	12-13	233	196	283	218	158	159	29
Vanuatu	40-44	35	23	21	11	–	–	–
Yugoslavia	30 +	19	25	27	30	30	31	31
Zaire	30-57	182	38	–	–	16	31	4
Total	NAp	15,025	13,181	12,454	14,624	15,047	12,834	11,564

[e] Estimated NAp Not applicable – Negligible
[1] Minor amounts (less than 500 tons) were also produced by Pakistan, Peru, and Sudan.
[2] Ferruginous manganese ore and manganiferous iron ore.
Source: Reference 19. Converted from short tons by the factor short tons × 0.907 = metric tons.

Table 2.—Market economy country manganese ferroalloy production, 1976–81
(Thousand tons)

Country	1976		1977		1978		1979		1980		1981[e]	
	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn	FeMn	SiMn
Argentina	24	6	36	6	25	10	37	16	35	15	34	14
Australia	50	15	71	24	95	–	86	20	86	19	85	19
Austria	8	–	7	–	7	–	9	–	8	–	8	–
Belgium	84	–	55	–	87	–	90	–	85	–	90	–
Brazil	99	63	129	75	118	106	133	128	141	134	128	122
Canada	80	–	60	–	70	–	41	–	86	–	109	–
Chile	8	2	5	–	5	–	5	–	5	–	5	–
France	365	12	358	21	390	19	440	13	470	21	315	9
Germany, Federal Republic	280	–	225	–	225	–	223	–	225	–	233	–
India	176	–	193	10	220	3	189	5	162	5	209	9
Italy	78	42	75	40	90	43	89	54	83	45	81	54
Japan	632	373	527	334	455	303	603	299	569	310	570	283
Korea, Republic	29	–	36	–	47	–	53	–	54	–	64	–
Mexico	54	17	100	27	107	34	123	31	125	31	125	30
Norway	348	169	244	127	273	133	337	184	296	168	224	198
Peru	–	–	–	–	1	–	1	–	1	–	1	–
Portugal	55	2	55	5	78	15	75	15	74	17	73	18
South Africa	350	22	310	22	330	22	560	45	500	60	450	50
Spain	133	91	141	63	134	109	148	119	120	123	92	63
Sweden	–	7	–	–	–	–	–	–	–	–	–	–
Thailand	2	–	1	–	1	–	1	–	–	–	–	–
Turkey	–	–	1	–	1	–	1	–	1	–	1	–
United Kingdom	122	–	69	–	69	–	137	–	52	–	91	–
United States	438	117	303	109	248	129	288	150	171	171	175	157
Venezuela	–	–	–	–	–	–	1	1	2	2	2	2
Yugoslavia	–	–	54	9	36	28	45	29	44	28	54	29
Zimbabwe	–	–	–	–	–	–	3	–	3	–	2	–
Total	3,437	964	3,055	872	3,112	954	3,718	1,109	3,397	1,149	3,221	1,057

[e] Estimated. – Negligible.
Source: Reference 18. Converted from short tons by the factor: short tons × 0.907 = metric tons.

are not available on the amounts produced at specific grades, it is difficult to determine the average manganese content. It is estimated that average annual production of about 13.7 million tons from 1976 to 1982 would contain an annual average of 5.0 to 6.0 million tons of manganese (5.3 million tons in 1981). The weighted average grade of the ores and concentrates produced from the mines and deposits in this study is about 44 pct contained manganese.

The United States is almost totally dependent on imports for its supply of manganese. Production of ore is limited to manganiferous iron ore. The average grade of all ore produced in the United States in 1980 and 1981 was about 12 to 13 pct manganese. This ore was used in various ceramic applications, such as brick coloring, and for direct additions to the blast furnace. Ore imports by country vary considerably from year to year; in 1981 and 1982 South Africa was the largest supplier of metallurgical ore.

MANGANESE FERROALLOYS

Ferromanganese and silicomanganese account for nearly all the manganese ferroally production. Market economy country production of manganese ferroalloys from 1976 through 1981 is shown in table 2.

As can be seen in the table, production of ferroalloys has increased in the ore-producing countries of Australia, Brazil, India, Mexico, and South Africa. The other ore-producing countries of Gabon and Ghana as yet have no smelting facilities. The largest consistent U.S. sources of ferromanganese are South Africa and France.

GEOLOGY

Manganese deposits are classified into four geological types: hydrothermal, residual, metamorphic, and sedimentary (*15*, pp. 10–14). Hydrothermal manganese deposits are normally made up of carbonates and oxides of manganese minerals along with other hydrothermal minerals such as barite, fluorite, and sulphides. Examples of hydrothermal vein-type and replacement deposits include the rhodochrosite ore at Butte and Phillipsburg, MT.

Residual deposits are formed near the surface by weathering processes. Large deposits of economic significance include the Serra do Navio Deposits in Brazil, Moanda in Gabon, Nsuta in Ghana, and several occurrences in Australia and India.

Metamorphic occurrences are generally in the form of low-grade silicates and rarely if ever have any economic value.

Sedimentary manganese deposits contain the largest portion of world economic manganese. These deposits are subdivided into several subclasses as shown below:

1. Volcanogenic deposits are those in which the manganese can be related directly or indirectly to volcanic sources. The Nsuta Mine in Ghana is considered to be in this class.

2. Nonvolcanogenic sedimentary deposits include those where the manganese is not related to any volcanic source. The more important manganese deposits of this type include Groote Eylandt in Australia, the Morro do Urucum area in Brazil, and the Maharashtra-Madhya Pradesh area in India.

3. Metasedimentary manganese deposits associated with iron formations are identified in Brazil and South Africa. The iron formation units are entensive and cover relatively great distances; however, the associated manganese beds within these formations vary in thickness and continuity.

4. Ocean floor nodules cover vast areas in the Pacific, Atlantic, and Indian Oceans. The nodules are found at all depths of the ocean, but higher grades are usually found within the deeper basins at great distances from land areas.

RESOURCES

Resources are defined according to the mineral resource-reserve classification system developed jointly by the U.S. Geological Survey and the U.S. Bureau of Mines (*21*). This classification is shown diagramatically in figure 1. The position of the resources included for this study is shown by the crosshatched areas.

The selection of 23 foreign and 8 domestic mines and deposits for this study includes over 98 pct of the known demonstrated resources at current mining grades for market economy countries. In terms of contained manganese, deposits evaluated in this study contain 780 million tons of demonstrated (measured plus indicated) and 994 million tons of identified (measured plus indicated plus inferred) resources (fig. 2). The demonstrated resources evaluated in this study by country are illustrated in figure 3.

Manganese resource estimate compilations have been made by several organizations. Correlation of these compilations with each other and this study in many cases is quite difficult, if not impossible, because of the different classification criteria used.

A summary of world manganese resources was made by the U.S. Geological Survey in 1973 (*5*). A later world estimate was made in 1979 as a combined effort by the U.S. Geological Survey and the U.S. Bureau of Mines (*4*). The South Africa Minerals Bureau also presented an estimate of world resources in 1979 (*6*). The most recent comprehensive study (1981) was completed by the National Materials Advisory Board (*15*).

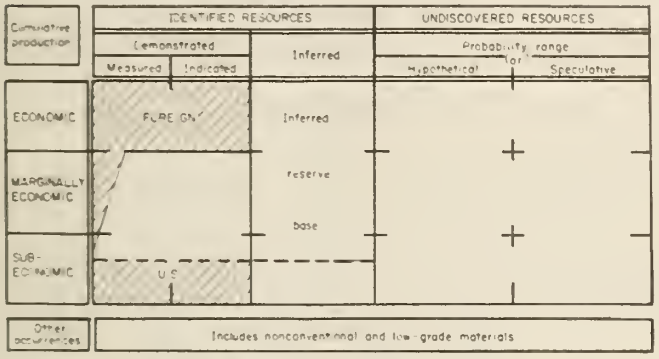

Figure 1.—Joint U.S. Geological Survey-Bureau of Mines resource classification system.

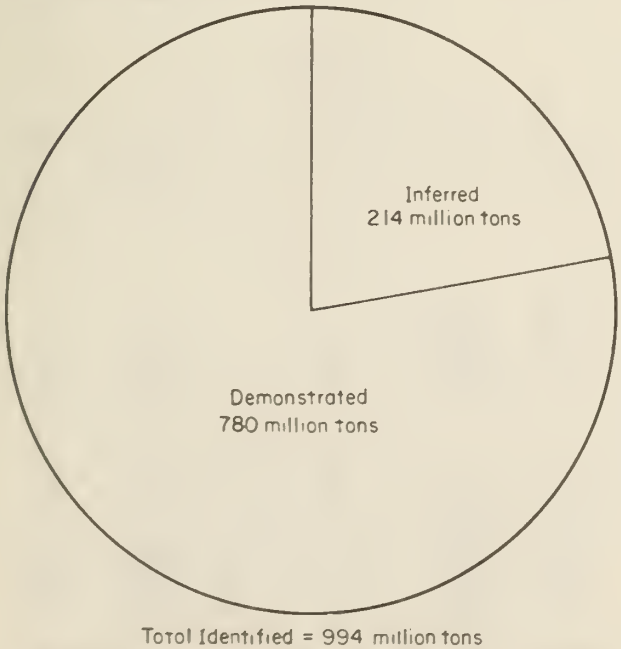

Figure 2.—Relationship of demonstrated and identified resources included in this study (in situ contained manganese).

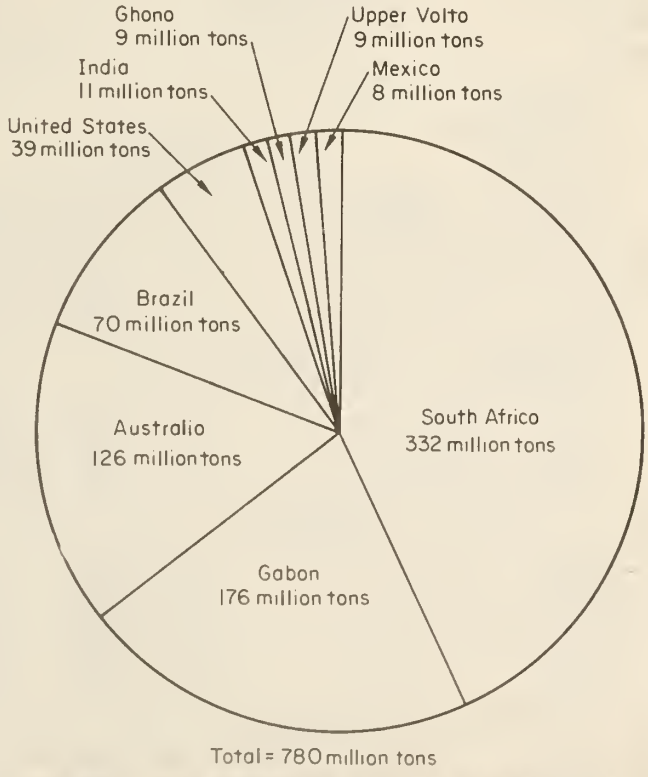

Figure 3.—Demonstrated ore resources evaluated in this study, by country (in situ contained manganese).

Table 3.—Reserve-resource classification categories by organization

Organization	Reserves and/or resource classifications	
U.S. Geological Survey (1973).	Reserves and conditional and hypothetical resources.	
Bureau of Mines-Geological Survey (1979).	Reserves and other (resources).	
South Africa Minerals Bureau (1979).	Reserves and resources.	
National Materials Advisory Board (1981).	Measured, indicated, and inferred reserves and submarginal and hypothetical resources.	
Minerals Availability Study (1980).	Demonstrated resources (measured plus indicated)	Identified resources (measured plus indicated plus inferred)

Source: References 4-6 and 15.

A summary of the manganese resource classification used by these different organizations is shown in table 3. The table illustrates a difficulty in correlating manganese resource estimates because there are no established standards for the categorization of in situ manganese ore resources. Resources are reported in terms of ore, product, contained manganese in ore or product, or a mixture of any of these. In addition, classification includes reserves, resources, measured, indicated, inferred, other, conditional, hypothetical, etc., all assessing the same material and from essentially the same sources of data.

Table 4 contains the total demonstrated and identified resources of mines and deposits in market economy countries as interpreted from published and other available sources. The resources analyzed for this study are identified by footnote 5. The demonstrated resources

Table 4.—Market economy country manganese mine and deposit data

Country and mine or deposit	Owner and/or operator	Map index[1]	Deposit status[2]	Annual output capacity as of 1981, thousand tons	Type of operation[3]	Average in situ grade, pct Mn	Resources,[4] million tons			
							Demonstrated		Identified	
							In situ material	Contained manganese	In situ material	Contained manganese
Australia:										
Groote Eylandt	Broken Hill Proprietary Co.	20	Prd	2,500	OP	41	308	[5]126	490	201
Brazil:										
Azul-Buritirama-Sereno	Companhia Vale do Rio Doce (CVRD).	11	Expl	NA	NA	42	65	[5]27	65	27
Santana	Compania Pavulista de Ferro Ligas.	12	Prd	120	UG	46	5	[5]2	30	14
Serra do Navio	Industria Comercio e Minerios S.A. (ICOMI).	10	Prd	1,200	OP	39	23	[5]9	23	9
Urucum	CVRD	12	Prd	250	UG	45	72	[5]32	102	46
Total Brazil	NAp	NAp	NAp	1,570	NAp	NAp	165	70	220	96
Gabon: Moanda	Cie. Minière de l'Ogooue (Comilog).	15	Prd	2,300	OP	44	400	[5]176	467	205
Ghana: Nsuta	Ghana National Manganese Corp.	17	Prd	300	OP	31	30	[5]9	30	9
India:										
Maharashtra-Madhya Pradesh area (includes Balaghat, Kandri, Munsar, Tirodi, Ukwa).	Manganese Ore India, Ltd.	18	Prd	320	OP/UG	46	10	[5]5	20	9
Karnataka (Mysore):										
Bisgod	Mysore Minerals Ltd.	17	Prd	45	OP	44	2	[5]1	2	1
Keonjhar District	Various owners	19	Prd	300	OP	40	12	[5]5	20	8
Total India	NAp	NAp	NAp	665	NAp	NAp	24	[5]11	42	18
Mexico: Tetzintla-Molango	Compani Minera Autlan.	9	Prd	550	OP/UG	28	30	[5]8	230	69
South Africa:										
Black Rock area (includes Gloria, Nchwaning, Nchwaning West)	Associated Manganese Mines of South Africa Ltd. (AMMOSAL).	16	Prd	2,000	UG	44	132	[5]58	132	58
Southern Farms	do	16	Ppd	NAp	NAp	33	10	3	10	3
Other AMMOSAL[6,7]	do	16	Expl	NAp	NAp	36–40	7	3	7	3
Do[6,7]	do	16	Expl	NAp	NAp	30–40	12	4	12	4
Do[6,7]	do	16	Expl	NAp	NAp	38–40	377	147	509	199
Do[6,7]	do	16	Expl	NAp	NAp	30–38	402	137	1,913	650
Do[6,7]	do	16	Expl	NAp	NAp	20–30	126	32	1,400	350
Mamatwan	South African Manganese Amcor, Ltd. (SAMANCOR).	16	Prd	2,200	OP	38	433	[5]165	433	165
Middleplaats	do	16	Prd	1,000	UG	38	40	[5]15	40	15
Wessels	do	16	Prd	1,125	UG	44	208	[5]92	208	92
Lohathla	do	16	Prd	520	OP	33	5	[5]2	5	2
Other SAMANCOR[6,7]	do	16	Expl	NAp	NAp	36–40	11	4	11	4
Do[6,7]	do	16	Expl	NAp	NAp	36–40	19	7	19	7
Do[6,7]	do	16	Expl	NAp	NAp	30–38	614	209	2,992	1,017
Do[6,7]	do	16	Expl	NAp	NAp	20–30	200	50	2,163	541
Do[6,7]	do	16	Expl	NAp	NAp	30–38	179	61	852	290
Other companies[6]	South African Iron and Steel Industrial Corp. Ltd. (ISCOR).	16	Expl	NAp	NAp	20–30	104	26	1,159	290
Do[6]	Minerts	16	Expl	NAp	NAp	44	20	9	20	9
Do[6]	do	16	Expl	NAp	NAp	30–38	51	17	244	83
Do[6]	do	16	Expl	NAp	NAp	20–30	62	16	693	173

See footnotes at end of table.

Table 4.—Market economy country manganese mine and deposit data—Continued

Country and mine or deposit	Owner and or operator	Map index[1]	Deposit status[2]	Annual output capacity as of 1981, thousand tons	Type of operation[3]	Average in situ grade, pct Mn	Resources,[4] million tons			
							Demonstrated		Identified	
							In situ material	Contained manganese	In situ material	Contained manganese
South Africa—Con.										
Other companies[6]—Con.										
Do[5]	Armco Bronne	16	Expl	NAp	NAp	30–38	51	17	241	82
Do[6]	do	16	Expl	NAp	NAp	20–30	40	10	446	112
Do[6]	Texas. Gulf	16	Expl	NAp	NAp	30–38	9	3	42	14
Do[6]	do	16	Expl	NAp	NAp	20–30	7	2	77	19
Total South Africa	NAp	NAp	NAp	6,845	NAp	NAp	3,119	1,089	13,628	4,182
United States:										
Hardshell	([8])	8	Expl	NAp	NAp	15.0	6	[5]1	6	1
Maggie	Arizona Manganese Corp.	7	Expl	NAp	NAp	8.8	8	[5]1	8	1
Sunnyside	Standard Metals Inc.	5	Expl	NAp	NAp	10.5	25	[5]3	40	4
Maple Mountain-Hovey Mountain.	Various owners	3	Expl	NAp	NAp	8.9	260	[5]23	260	23
North Aroostook District (Dudley and Gelot Hill).	Various owners	4	Expl	NAp	NAp	9.5	63	[5]6	63	6
Cuyuna North Range (southwest portion).	([8])	2	Expl	NAp	NAp	7.8	49	[5]4	140	11
Butte district (Emma Mine).	The Anaconda Co.	1	Expl	NAp	NAp	18.0	1	[9]0	1	[9]0
Three Kids	Income Investment Inc.	6	Expl	NAp	NAp	13.2	7	[5]1	15	2
Total United States.	NAp	NAp	NAp	NAp	NAp	NAp	419	39	533	48
Upper Volta:										
Tambao	Société Minière de Tambao.	13	Expl	NAp	NAp	54	16	9	29	16
Grand total	NAp	NAp	NAp	14,730	NAp	Nap	4,511	1,537	15,671	4,844

NAp Not applicable.
[1] Refer to figure 4.
[2] Status of deposit: Prd — operating, Expl — explored, Ppd — past producer.
[3] Type of operation: UG — underground, OP — open pit.
[4] Rounded to nearest 1 million tons.
[5] Resources used in this study.
[6] "Other" refers to resources that are not delineated by location, thickness, specific grade, depth, etc, or that are below current mining grade.
[7] Manganese grade ranges averaged as follows for contained manganese, in pct:

Range	Average	Range	Average
36–40	38	30–38	34
30–40	35	20–30	25
38–40	39		

[8] Property not under ownership.
[9] Less than 500,000 tons contained manganese.

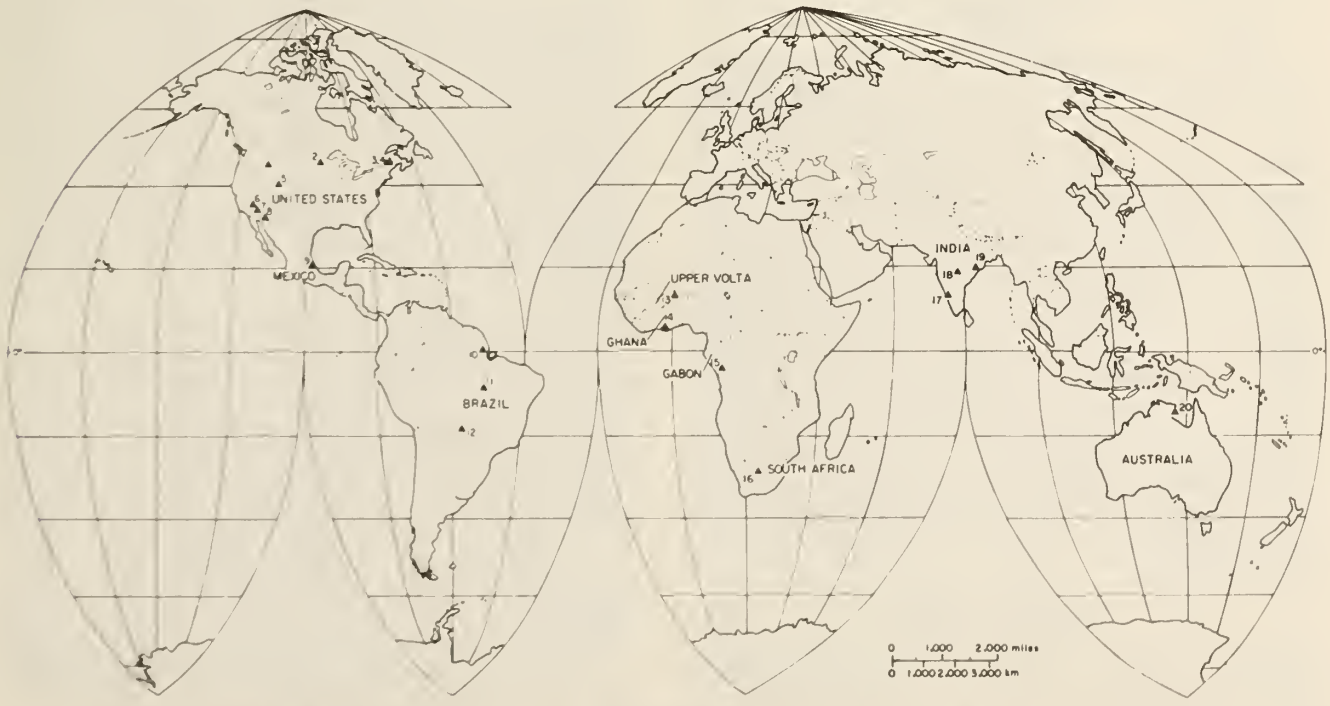

Figure 4.—Location of market economy country manganese mines and deposits; index numbers refer to table 4.

used in this study are based on estimates of quantities existing in the foreign mines and deposits at or above current mining grades shown for the producing mines in table 4; the U.S. deposits contain about 12 to 13 pct manganese. The resource locations are shown in figure 4.

The resources used in this study compared to total published resources listed in table 4 are shown below (in million tons of contained manganese):

	Demonstrated	*Identified*
Resources evaluated in this study ..	780	994
Total resources (table 4)	1,537	4,844

In the total demonstrated resources (contained manganese) there is a difference of about 757 million tons (1,537 minus 780), which is accounted for by the difference in classification of materials in South Africa. This results from the inclusion of resources in the total quantity that are below the current mining grade or that cannot be defined as to location, dimensions, depth, ore thickness, etc.

The resources used for South Africa are an adaptation of data published by Taljaardt (*16*) in which the resources are identified by ore types, grade, and various company ownership. The ore types include the Wessels, which is of higher grade with a relatively high iron content, and the Mamatwan, which is lower grade with a low iron content.

In the Wessels category 340 million tons of plus 40-pct-Mn material were analyzed in this study, or about 83 pct of the Taljaardt estimate of 409 million tons.

In the Mamatwan category 473 million tons of 38- to 40-pct-Mn material were used in this study, or about 3.6 pct of the Taljaardt total estimate of 13.2 billion tons in grades of 20 to 40 pct Mn. Taljaardt estimated a total of 982 million tons of Mamatwan-type ore at 38 to 40 pct Mn, of which only the 473 million tons used could be identified as to location, thickness, depth, etc.

Even with the varied interpretations of resource data by different organizations, land-based manganese resources of the market economy countries are vast in comparison with future requirements. In fact, only seven major operations, Serra do Navio in Brazil, Groote Eylandt in Australia, Moanda in Gabon, and the Black Rock area (three mines), Wessels, Middleplaats, and Mamatwan Mines in South Africa, after allowing for mine and mill recoveries, could supply the market economy estimated demand for at least 80 years based on 1976–81 average production.

The grade ranges and resource quantities estimated by Taljaardt for the Wessels and Mamatwan ore types follow:

Ore type and grade, pct Mn	*Estimated resource quantity, million tons*
Wessels:	
+44	330
40 to 44	30
36 to 40	18
30 to 40	31
Total	409
Mamatwan:	
38 to 40	982
30 to 38	6,286
20 to 30	5,938
Total	13,206

COUNTRY MANGANESE RESOURCE SUMMARY

AUSTRALIA

The principal manganese deposit in Australia is the Groote Eylandt, owned by Broken Hill Proprietary Co. Ltd. and operated by a subsidiary, Groote Eylandt Mining Co. Ltd. The mine has been in operation since 1966. A number of smaller deposits not included in this study are located in Western Australia, Queensland, New South Wales, Victoria, and South Australia.

The Groote Eylandt Deposit occurs as a relatively flat tabular stratum deposited over an irregular basement rock. Sandy clay and laterized conglomerates which vary in thickness and lateral extent overlie the ore body. The ore in turn lies on consolidated sands and clays with claystones and mudstones; the principal ore minerals are pyrolusite, cryptomelane, and psilomelane (*12*).

It is estimated that there was approximately 308 million tons of demonstrated material remaining as of January 1980, containing an average of 41 pct manganese. There is possibly another 110 million tons in other areas of the deposit that have only been minimally explored (*12*).

The deposit is mined by open pit methods and is worked in a series of separate quarries for grade control. The mine has a capacity of about 5 million tons of ore per year and can produce about 2.5 million tons of product. It is estimated that to mine the total resource the cumulative waste-to-ore ratio will be about 2.5 to 1. The maximum haulage distance to the concentrator is about 20 km.

The concentrator consists of four sections: crushing, feed preparation by washing and screening, scrubbing and dewatering, and heavy-media separation. The concentrator produces products of varying grades in both lump and fine sizes. The concentrate grades vary from a little over 41 pct to about 52 pct. A high-silica lump product is also produced that is used in the production of silicomanganese. The concentrate is hauled about 16 km to a storage area near the port where the various grades are reclaimed, blended, and shiploaded by conveyor.

The high-carbon ferromanganese capacity of Australia is about 115,000 tons per year. This is produced in three Bell Bay (Tasmania) plants operated by Tasmanian Electro Metallurgical Co. Proprietary Ltd. An additional 25,000 tons per year of silicomanganese can be produced as a byproduct of the high-carbon process. Estimated ore requirements would be about 360,000 to 370,000 tons, or about 15 pct of the mine output capacity.

The largest export markets are Japan and Asia, which have in the past consumed about 40 pct of the production. The remainder is shipped to Europe and the United States.

There are no known plans for increasing smelting capacity in Australia. Smelting capacity required to

utilize all the Groote Eylandt output would be approximately 1 million tons per year.

BRAZIL

The principal manganese resources of Brazil occur in the Serra do Navio Mine of Amapa, the Urucum and Santa Mines of Bahia, and the Azul, Buriturama, and Sereno Deposits in the Carajas Mineral Province of Para. Numerous other manganese deposits occur in the States of Minas Gerais, Bahia, Goias, and Espirito Santos, but because of their small size, they were not included in this study.

Data on production from separate areas are apparently not reported on a common base and thus are difficult to interpret. In 1979, total ore production was reported as approximately 2,260,000 tons, from which about 1,700,000 tons of concentrates and pellets was shipped. Of this quantity, 1,189,800 tons was shipped from the Serra do Navio Mine. The remaining production was from numerous mines in the States of Minas Gerais (about 400,000 tons), Bahia, Mato Grosso, Goias, and Espirito Santo.

Serra Do Navio Mine

The Serra do Navio Mine is located in the Amapa Territory and is the largest producer of manganese concentrates in Brazil. The mine is owned and operated by Industria Comercio e Minerios S.A. (ICOMI), which is a joint venture between Cia. Auxiliar de Empresas Mineracao (Caemi), a Brazilian company, and Bethlehem Steel. Initial development began in 1952 and production in 1957. A pellet plant for upgrading previously discarded fines to about 54 pct manganese was put on stream in 1973.

The deposit is part of the Precambrian Guyana Shield, consisting of a metasedimentary sequence of gneisses, amphibolites, schists, and quartzites. These sedimentary units alternate in a relatively cyclic pattern and are subdivided into three distinct facies: quartzose, biotitic, and graphitic. The major ore minerals are cryptomelane and pyrolusite. Minor manganiferous minerals include hausmannite, lithiophorite, and manganite. These deposits are classified as residual lateritic concentrations.

The mining area contains about 20 ore bodies distributed along a belt about 12 km long up to 70 m wide. Typically the ore bodies are fairly dense and compact but show stages of variations from dense to porous friable material.

Mining operations are rotated to some extent on a seasonal basis. During the rainy season (January through June), activities are concentrated on mining; stripping receives major emphasis during the dry season. The ore is concentrated at the mine by crushing, screening, and washing. The minus 1.2-mm material is stockpiled for use in pelletizing feed, and the plus 1.2- to minus 8-mm material is either shipped as sinter feed or used as pellet plant feed as conditions warrant.

The pellet plant is located at the port of Santana, about 200 km from the mine. Here the processes include cyclones, screens, heavy media, and spirals, followed by reduction roasting, magnetic separation, and pelletizing. The pellets contain about 54 pct manganese.

The remaining in situ demonstrated resources are estimated at approximately 23 million tons including stockpiled fines (*7*, p. 11), which would last about 8 to 10 years at a 2.5-million-ton-per-year mine capacity. Another 6 to 7 years of pellet production is possible from the fines stockpile at a product capacity of 200,000 tons per year. All the concentrates are shipped by rail to Santana, where they are loaded on ships for export.

The approximate 1.2 million tons of concentrates available annually in the Serra do Navio Mine should be more economically shipped to the United States than to other areas. In recent years, though, only about 10 pct has been shipped to the United States. The majority is shipped to Europe. In 1980, about 64 pct was shipped to Europe, 11 pct to Japan, 6 pct to the United States, 17 pct to Brazilian ports, and the remainder to other South American ports. In 1981, the export destinations were Europe—70 pct, Japan—15 pct, United States—13 pct, and 2 pct to other South American countries, with none shipped to Brazilian ports.

Azul, Buriturama, and Sereno Deposits (Carajar Minerai Province)

The Azul Deposits in the Carajas area of Para State lie between the north and south limbs of a synclinorium composed of Precambrian sediments, iron formations, and volcanic rocks. The manganese deposits lie above manganiferous pelitic shales that uncomformably overlie the Precambrian sediments. The in situ ore was derived from weathering of two shale protore beds with grades ranging from 14 to 36 pct manganese and an intervening layer grading about 2 to 4 pct manganese.

The Buriturama deposits, consisting of nine separate ore bodies, appear to be the product of weathering and are an enrichment of a manganese carbonate-silicate protore.

The Sereno Deposits are genetically similar to the Buriturama deposits, but are much smaller and more scattered. Resources for the separate areas follow (*7*):

Deposits	*Quantity, million tons*	*Grade, pct Mn*
Azul	65	42
Buriturama	11	39
Sereno	2.8	30

Exploitation of these deposits is not expected until a 900-km railroad from the coastal city of Sao Luis to the Carajas Iron District is completed. This railroad is presently under construction and is projected to initiate the development of some 18 billion tons of iron ore in the area (*14*, pp. 16–18). It is estimated that to develop the manganese in this area would require an investment of about $40 million, including the construction of a 30-km railroad and other infrastructure. Mining capacity is assumed at about 1 million tons per year.

For this study, only the Azul Deposit containing 65 million tons was used. It was assumed that mining would be by open pit methods, that milling would consist of crushing and screening, and that 50 pct of the concentrates would be consumed in Brazil; the remaining 50 pct would be shipped to Europe and the United States.

Santana Mine

The Santana Mine is located in a remote area of Mato Grosso near the Bolivian border and is owned by Cia.

Paulista de Ferro-Ligas, which also owns the smelters through which the material is processed.

The manganese bed at the Santana Mine, probably the lower bed of the Morro do Urucum Formation, can be traced over a distance of 650 m along an outcrop. The manganese bed dips 15° to the east and ranges in thickness from 2.5 to 4.0 m, with most of the manganese oxides concentrated in the lower part of the bed. The major ore mineral, cryptomelane, occurs as thin irregular layers and roughly stratified layers of nodules in a matrix of coarse sand and clay derived from weathered arkose.

The Santana Mine has produced both hematite float and manganese ore for several years. The ore is mined by underground room-and-pillar methods from adits, and current capacity is 120,000 tons per year. Output from the Santana Mine is converted to ferromanganese in two company-owned electric smelting plants in the Corumba area and in smelters in other locations.

Demonstrated resources of the Santana Mine are estimated at 5 million tons. Nearby properties have reported a total of about 30 million tons of resources, which reportedly could be increased by some 30+ million tons by more detailed exploration (*7*, p. 16). At this time, there are too few data available to adequately delineate these other deposits for inclusion at the demonstrated level for this study.

Urucum Mine

The Urucum Mine is located in Mato Grosso in the same area as the Santana Mine. The manganese occurs in a mesalike mountain of sedimentary rock series. The deposit was first mined in 1912 and had intermittent periods of production through 1972. In 1976, mining was restarted by Companhia Vale do Rio Doce (CVRD).

Three manganese beds with thickness ranging up to 6 m occur in this area. The manganese oxide beds are almost all intercalated between clastic beds in an iron formation. Average analysis of the manganese oxide lenses in the Urucum area is about 46 pct manganese. The principal mineral is cryptomelane.

The ore is mined by room-and-pillar methods. The mine is developed and mined through parallel adits driven along the strike. The ore is broken and removed prior to breaking and removal of the waste to prevent dilution. Rooms are turned off from the adits at right angles every 15 m. Stope pillars are 4 by 4 by 4 m wide, and the rooms are 60 m long. With the present equipment and mine development, the mine has a maximum annual capacity of 260,000 tons and contains an estimated resource of 72 million tons (*7*, p. 14). The ore is beneficiated by simple crushing and screening.

The ore from this mine can be shipped either 1,500 to 1,700 km by rail to Rio de Janeiro or Sao Paulo for domestic use, or 2,700 km by barge (seasonal) to Nueva Palmira, Uruguay, for export. The ore contains 3 to 4 pct alkalies that must be diluted by blending.

For the economic evaluation in this study it is assumed that 50 pct is transported by barge through Paraguay for export. The remainder is transported by rail for domestic use.

Other Mines

Aside from the more important manganese deposits discussed above, Brazil has numerous smaller mines which supply domestic requirements. These small deposits are scattered through the States of Minas Gerais, Bahia, Goias, and others. The estimated resources from individual States follow (*7*, p. 29):

Area	*Quantity, million tons*	*Grade, pct Mn*
Minas Gerais	5.5	31
	6	35
	5	30
Bahia	15	38
Goias	10	33

With the development of the Urucum and Azul areas, Brazil could maintain current production levels after the depletion of the Serra do Navio resources, although at higher costs mainly because of the longer transportation distances.

Brazil's current annual smelting capacity is 140,000 tons of ferromanganese and 180,000 tons of silicomanganese, which requires a feed of about 560,000 tons of ore and concentrates at full capacity. Part of this is supplied by a number of small mines that have relatively insignificant resources. The remainder is supplied by the mines in the Urucum area.

Brazil has projected a progressive increase in its manganese ore, ferromanganese, and steel production. Because of vast iron ore resources, the near-future expansion of the steel industry is more probable than the expansion of the manganese industry. Future developments in the manganese industry will probably depend on the domestic iron industry, such as development of the Carajas iron ore area. Increases in mine production will be restricted by high transportation costs, since the major resources are located in remote areas.

GABON

The Moanda Mine in Gabon is owned and operated by Comilog, a company jointly owned by U.S. Steel, Bureau de Recherches Géologiques et Minieres (BRGM), Imetal S.A., other French interests, and the Gabon Government.

The manganese occurs in five deposits within the Francevillian Series, and the principal ore minerals are pyrolusite, manganite, and cryptomelane.

The ore is mined at the Bangombe Deposit by open pit methods and is excavated in a series of rectangular trenches running from 610 to 915 m in a north-south direction. Each trench measures 20 m wide and is worked from east to west by walking draglines. Ore from the mine is trucked to the crusher station, where it is reduced to 6 mm size. The crushed material is then fed to cleaning drums, where water is introduced countercurrently. The washed material is then classified through vibrating screens to different product sizes with fines upgraded in a heavy-media separation circuit. The minus 6-mm material is currently being stockpiled as waste; about 10 million tons had been stockpiled as of 1979 (*15*, p. 177).

With current annual mine production capacity of 4 million tons (about 2.3 million tons of product) and a demonstrated resource of 400 million tons (*6*, p. 40; *15*, p. 178), the deposit will sustain a mine life of at least 100 years. Annual mine production rate in 1982 was about 3.5 million tons of ore.

The mine product is transported 78 km by aerial ropeway and 485 km by rail to Pointe Noire in The Republic of Congo for export.

In addition to the ore treatment plant, a concentration plant was installed to treat about 100,000 tons per year of washed ore sized to plus 6 mm minus 20 mm for use in dry cell batteries.

The advantages of this mine are the high degree of mechanization and the abundant reserves of high-grade ore, along with significant quantities of battery-grade ore. One limiting factor is the relatively long distance to transport the concentrates to smelter installations. Gabon has no smelting facilities. The Trans-Gabon railway (560 km), which would serve the Moanda area, is scheduled for completion in 1987. With this railroad the mine capacity could be increased to at least 4 million tons per year of product.

GHANA

The manganese ore deposits of the Nsuta Mine are located about 62 km from the port of Takoradi and are owned by Ghana National Manganese Corp. The deposits occur on five hills and can be traced almost continuously for about 4 km. The hills are elevated 60 to 90 m above the surrounding area and are interconnected by saddles.

The principal ore bodies that have been mined in the past are sedimentary lenses rich in battery-grade manganese oxides from Recent or Tertiary laterizations and oxide enrichment of gondites. The major manganese mineral in the remaining resources is rhodochrosite.

The mine has operated for over 60 years and has been one of the major suppliers of battery-grade oxide ore, but the reserves of this type of ore are nearly mined out. The evaluation in this study was based on approximately 30 million tons of carbonate ore underlying the oxides (*6*, p. 76).

In recent years, the carbonate ore has been mined and processed for the manufacture of electrolytic manganese dioxide in plants in Japan and Ireland. Production in 1982 was about 22,000 tons of oxide ore and 138,000 tons of carbonate ore. The carbonate ore is processed by crushing, washing, screening, and hand sorting.

At the Nsuta Mine, the Ghana National Manganese Corp. has completed a nodulizing plant which will convert the carbonate ore to oxide by roasting. The plant was completed in 1982 but has not been commissioned because of the lack of electric power. As of 1982, a 2-year plant feed supply had been stockpiled, with production anticipated in 1984.

From this plant, it is expected that 300,000 tons of manganese oxide nodules from 450,000 tons of carbonate ore will be produced annually (*23*). The nodules will be transported about 62 km by rail to the port of Takoradi for export. This is a relatively short distance; however, the railway system experiences frequent breakdowns.

The beneficiation costs for this resource are relatively high in that the ore must be nodulized; however, this beneficiation increases the grade from about 31 to about 44 pct manganese. For this study it it estimated that about 80 pct of the concentrates will be destined for Europe and the remaining 20 pct will be sent to Japan.

INDIA

Manganese ore mining in India is characterized by many small mine operators mining and sorting ores by hand methods. With over 300 individual mines in various stages of selective hand mining, it is difficult if not impossible to interpret resource data. In addition, no systematic geological mapping or drilling program has been done on the majority of the existing deposits.

In general, resources are outlined in the immediate vicinity of the mine areas, based on ore exposures. All other data are estimated on the basis of geologic inference. As a result, most information indicated a great difference (4 to 10 times) between indicated and inferred resources. Estimates of inferred resources generally include wide areas and are not deposit specific.

Mining and processing of the manganese ores is generally done by hand because labor is cheap and production of individual mines is not large enough for the use of mechanical methods.

India has an annual smelting capacity of about 307,000 tons of high-carbon ferromanganese and about 43,000 tons of silicomanganese. This includes the 72,000-ton-per-year plant under construction at Tumsar. Total ore requirements to feed the smelting capacity of India would be about 810,000 tons. This is approximately 50 pct of the ore production of India, and thus it is assumed that about 50 pct of the ores are exported.

Much of the production of high-grade manganese ore in India has been designated for use within the country in recent years. The only ore exported is that containing less than 46 pct manganese. The future capability of production cannot be predicted with any certainty because of the lack of a definitive resource base. Manganese production in India has remained relatively constant since the early 1950's without any significant changes in the known reserves. Without systematic exploration or mechanized mining methods in the manganese industry, it is unlikely that significant increases in production could or will occur.

Because of extremely labor-intensive mining and processing methods, estimated to produce about 0.1 ton per worker-shift, the costs associated with these mines are much higher than those experienced in the mechanized mines in all the other countries studied.

In view of the vast number of small mining operations and limited demonstrated resources in India, it was not considered feasible within the scope of this study to attempt an evaluation that would include a major number of these operations. It is felt that the coverage included represents the current mining and processing practices in the manganese mining industry of India. This evaluation includes mines from three areas, the Maharashtra-Madhya Pradesh area of central India (five mines), the Keonjhar District in Orissa, and the Bisgod Mine in Karnataka.The mines in central India are operated by Manganese Ore India, Ltd. Most of the ores are relatively high grade and can be blended with lower grade, low-phosphorus ores of Orissa. Most of the ore in Karnataka is exported because of the high iron content and the lack of nearby smelting facilities (*22*, pp. 32–33).

Maharashtra-Madhya Pradesh Area

It is reported that this area produces about 75 pct of all high-grade ore in India (*22*, p. 34). Demonstrated resources for the area are estimated at 10 million tons. Generally, the mines described represent the main operation in a particular area. Ore is also supplied by numerous individually operated workings.

It is assumed that about 50 pct of this ore is smelted domestically, and the remainder is shipped to the ports of Visakhapatnam and Bombay for export to Japan and Europe.

Balaghat Mine

The Balaghat Mine is mainly an underground operation and extends over a strike length of 3.7 km. The ore comes from two types of deposits, lode or reef type, and detrital or float-type deposits. The ore consists of a mixture of several manganese oxides, with braunite being the principal mineral.

The mine operates on six levels, some of which have been developed to a strike length of 2.7 km, and produces about 114,000 tons annually. The ore is sorted and cleaned by hand and separated into different sizes and grades. The reject fines and tailings are relatively high grade. It is planned to build a beneficiation and an agglomerating plant to process this waste material. A ferromanganese plant also has been contemplated for the area.

Kandri Mine

The Kandri Mine is situated near the village of Kandri. The ore body occurs in a horseshoe-shaped synclinal exposure and has barren zone between its two limbs.

The ore zone ranges in thickness from 1.5 to 3.9 m near the bottom of the syncline. Over the exposed length of 230 m of the syncline, the ore-bearing horizon attains a maximum thickness of 22.5 m.

The ore was originally mined by opencast methods. Now, all mining operations are underground through an inclined shaft. Overhead, flat back, and cut-and-fill stoping methods are used to mine 30,000 tons annually. Mining is performed mostly by manual labor, but in recent years some mechanization has been introduced. Manual sorting and sizing are done at the mine, and the product is shipped to the Tumsar, Kahhua, and Kelsar ferromanganese plants.

Mansar Mine

The Mansar Deposit has an indicated strike length of 2.8 km. The ore body crops out on the surface as a band running almost northwest-southeast in an isoclinically folded and plunging formation with very high dips.

The ore is both hard and soft. The hard ore consists mainly of braunite granules cemented by psilomelane. Quartz is the main gangue mineral, and the ore contains high phosphorus and silica. On the average, the run-of-mine, unsorted ore represents 70 pct of the total thickness of the ore zone, and the balance is waste consisting of manganiferous quartzite. The marketable ore comprises roughly 30 pct of the ore body.

Mining is conducted by open pit and underground cut-and-fill methods. The combined annual production is 45,000 tons.

Tirodi Mine

All deposits in the Tirodi area are characterized by intensely folded, overturned, isoclinal, and recumbent folds. These deposits are exposed continuously over a distance of about 10 km. The main potential zone has a thickness of 2 to 3 m along a total strike length of 425 m. The manganese ore is very hard, compact, fine to coarse grained, and usually enclosed in schist. The deposit consists of a primary bedded manganese sequence with braunite as the principal mineral. The ore is generally high in phosphorus (above 0.2 pct), whereas the silica content is fairly low.

The Tirodi Deposit has been mined since 1901 using the open pit method. The bulk of the mining extraction is carried out manually, and even jackhammers and compressed air are rarely used. Underground cut-and-fill methods are being adopted in deeper sections of the deposit, consisting of levels 2.1 by 2.1 m in size driven laterally. The present combined annual production capacity for the mine area is estimated at about 90,000 tons.

Ore from the mine is broken by hand into about 10-cm lumps and processed by hand sorting. Mechanical washing is adopted during the rainly season using washing drums. This washing technique upgrades the ore by about 3 pct.

Ukwa Mine

Mining in the Ukwa area was started in 1906; continuous operation probably began in 1938 when a 29-km ropeway was installed. The Ukwa deposit extends over a strike length of about 5.5 km. In general, the thickness of the ore bed for the major portion of the strike length is 3.0 to 3.5 m. The greater part of the ore is in the form of psilomelane and braunite. The ore is fairly high in manganese, with phosphorus content varying from 0.07 to 0.1 pct. Annual ore production is about 39,000 tons. All mining is done by manual labor, including hauling. Upgrading is accomplished by hard sorting and jigging of the ore on the mine floor. The concentrate is transported by aerial tramway 29 km to the railhead at Balaghat and is shipped to Tumsar or Komptee for smelting or to Bombay for export.

Keonjhar District

The Keonjhar District in Orissa State contains about 200 open pit operations that are mined by a few major operators and a large number of individual miners.

The principal rock types in the Keonjhar District include quartzites, banded hematite, metavolcanics, highly folded shales of an iron ore series, and gently folded sandstone, phyllites, and shales. The manganese ore, together with associated iron ore, occurs as lenses, pockets, reefs, and veins in the shale, jasper, and quartzite formations. The most abundant mineral is psilomelane with some manganite.

The Keonjhar ores are characterized by low phosphorus and high iron content. The grade varies from deposit to deposit, but most of the ores are in the lower grade ranges. Only about 10 to 15 pct of the ores are suitable for ferromanganese production without blending (*22*, p. 32).

All mining operations are by open pit methods using manual labor. Current ore production from four major stratigraphic zones with the district is estimated at about 300,000 tons per year. The practice of removing the high-grade ore results in the loss of large tonnages of low- and medium-grade ores, which often become contaminated with waste materials. For this study, the resources of the Keonjhar District were estimated at 12 million tons.

It is assumed that 50 pct of the concentrates are exported through Visakhapatnam to Japan and Europe. Rail shipping distances are nearly the same for both export and domestic use.

Karnataka (Mysore) Area

The manganese deposits at the Bisgod Mine in Karnataka, owned by Mysore Minerals Ltd., are stratiform in nature and enclosed in laterite. The major mineral is psilomelane, with pyrolusite occurring in lesser amounts. The current mining method is opencast, and a large segment of the work is done by manual labor. Current production is estimated at 142 to 180 tons per day; as in other parts of India, part of the production is supplied from individual workings in the mine area. Most of the ore is high in iron and low in manganese, and about 75 pct of the product is exported. The exported concentrates are transported 140 km by small trucks to Beligondi, where they are loaded onto barges and then transloaded to ships. The remainder is shipped by rail to domestic plants in the area.

Other Mines

It is estimated that over 300 separate mines are being worked, of which about 290 are privately owned. Because of their small size, most of these mines were not included in this study. Total reserves for the larger of the mines not included have been reported as approximately 13 million tons, measured plus indicated, and approximately 52 million tons inferred (*14*).

MEXICO

Nearly all of Mexico's total output of manganese ore comes from the Tetzintla Mine located in the Molango district of the State of Hidalgo about 140 km southwest of Tampico and owned by Compania Minera Autlan, S.A. de C.V. Mineralization occurs over an area measuring 50 by 20 km at the base of the Chipoco Formation, although the manganese-bearing horizon may not occur throughout the entire area. At the Tetzintla Mine, the manganese-bearing section is about 7 m thick and averages about 28 pct manganese.

The ores are hard, compact, finely stratified manganiferous limestone. There are two types of manganese deposits in the Molango district. The most important is the fine-grained carbonate ore that is composed mainly of rhodochrosite, kutnahorite, and manganocalcite. The second type is rich oxide ore derived from the carbonate ores by oxidation and supergene enrichment. The oxide product from the Nonoalco Mine in the district is a source of manganese dioxide used for the production of dry cell batteries. About 40,000 tons per year of battery-grade ore are produced.

The Tetzintla Mine started production as an open pit mine in 1969, and in 1978 an underground room-and-pillar operation was developed in the Tetzintla ore body. The open pit mine has a capacity of 1,500 tons per day, while the underground operation has a capacity of 1,900 tons per day. Demonstrated resources of the district are estimated at 30 million tons (*15*, p. 93). This includes 15 million tons proven at the Tetzintla Mine. The concession area contains an additional estimated 200 million tons of similar material, which for this study is considered to be inferred. The concession area includes the Tetzintla Mine and the Naopa, Acoxcatlan, and Comextetzintla Deposits. The Naopa Deposit is in the planning stages for an open pit mine.

Normally the ore is crushed in three stages to minus 1.25 cm and fed into a rotary kiln at Otongo, where the carbonates are converted to oxides and nodules are formed. When excessive silica and alumina dilution is present, the ore is first upgraded to 27.5 pct manganese by heavy-media separation. The nodules contain 39 to 40 pct manganese (*1*).

Mexico has a smelting capacity of about 150,000 tons of ferromanganese and 50,000 tons of silicomanganese. The mine has a capacity to produce about 550,000 tons of nodules. Because of the low grade of the nodules, they must be blended with high-grade imported ore. It is estimated that about 75 pct of the output is exported. Marketing involves transporting the nodules about 230 km by truck to Tampico, from where they are shipped to domestic ferromanganese plants at Vera Cruz and exported to Japan, France, and the United States.

Within Hidalgo State, small amounts of manganese ore are mined at Pachuca. Minor amounts are also mined in the States of San Luis Potosi (Charcas), Chihuahua (San Buenaventura), and Zacatecas (Villa de Cos).

SOUTH AFRICA

Resources

The manganese resources of South Africa are considered vast, although there are differences in the resource interpretations of the available data. The resources occur mainly in two separate fields, the Kalahari and Postmasburg. Nearly all the resources are in the Kalahari Field. Probably the most complete assessment of the resources was estimated by Taljaardt (*16*) at over 13.6 billion tons of material through the inferred category, grading from 20 to over 44 pct manganese aggregated by company ownership and different grade range categories. Only deposits near the existing mines are fairly well investigated by exploration drilling. Further exploration will undoubtedly reclassify some of the material from inferred to demonstrated resources. In this study, these resources are allocated to the operating mines as shown in table 5.

The majority of the resources in South Africa are in grade categories lower than most of those currently being mined through the market economy countries. According to the data shown in table 5, the current mining grades (plus 38 pct Mn) account for 1,396 million tons, or about 10 pct of the total resource shown in the table. Of this total, 818 million tons is considered in this study. Based on current capacities (table 4), it will probably be 70 to 80 years before any development is needed on the lower grade type of ore. The relationship of the ores by grade is shown in figure 5.

Of the total resource of 13,628 million tons, 409 million tons (about 3 pct) is of the high-grade, high-iron Wessels type, and nearly all the remainder is low-grade, low-iron Mamatwan type. Resources in the Postmasburg Field account for less than 1 pct of the total. Of the current total production capacity, Wessels type accounts for 47 pct, Mamatwan type accounts for 45 pct, and the remaining 8 pct is from the Postmasburg Field.

The criterion used in the allocation of resources in South Africa for this study was the limitation of grades to those currently being mined. This limits the Wessels grades to plus 44 pct and 40 to 44 pct manganese, and the Mamatwan grades to 38 to 40 pct manganese. Lower grade ores are apparently produced by all operations, but

Table 5.—Estimated South African manganese resources, total and used in this study
(Million tons)

Type and grade, pct Mn	Company	Resources		
		Total quantity[1]	Used in this study	Mine
KALAHARI FIELD				
Wessels:				
Plus 44	SAMANCOR	184 P	184	Wessels
	..do.	6 I	6	Wessels
	AMMOSAL	120 E	120	Black Rock[2].
	Minerts.	20 E	([3])	NAp.
40 to 44	SAMANCOR	18 P	18	Wessels
	AMMOSAL	12 E	12	Black Rock[2].
36 to 40[4]	SAMANCOR	11 P	([5])	NAp.
	AMMOSAL	7 E	([5])	NAp.
30 to 40[4]	SAMANCOR	19 P	([5])	NAp.
	AMMOSAL	12 E	([5])	NAp.
Total	NAp	409	340	NAp.
Mamatwan:				
38 to 40	SAMANCOR	348 P	348	([6]).
	..do.	125 I	125	([6]).
	AMMOSAL	509 E	([3])	NAp.
30 to 38	SAMANCOR	614 P	([5])	NAp.
	..do.	2,378 I	([5])	NAp.
	AMMOSAL	1,913 E	([5])	NAp.
	ISCOR	852 E	([5])	NAp.
	Minerts.	244 E	([5])	NAp.
	Armco Bronne	241 E	([5])	NAp.
	Texas Gulf	42 E	([5])	NAp.
20 to 30	SAMANCOR	200 P	([5])	NAp.
	..do.	1,963 I	([5])	NAp.
	AMMOSAL	1,400 E	([5])	NAp.
	ISCOR	1,159 E	([5])	NAp.
	Minerts.	693 E	([5])	NAp.
	Armco Bronne	446 E	([5])	NAp.
	Texas Gulf	77 E	([5])	NAp.
Total	NAp	13,204	473	NAp.
Total Kalahari Field	NAp	13,613	813	NAp.
POSTMASBURG FIELD				
Postmasburg	SAMANCOR	5	5	Lohatla.
	AMMOSAL	10	([7])	Southern Farms.
Total Postmasburg Field	NAp	15	5	NAp.
Grand total	NAp	13,628	818	NAp.

NAp Not applicable.
[1] E = estimated; I = inferred; P = proven.
[2] Gloria, Nchwaning, Nchwaning West Mines.
[3] Not delineated as to location, depth of ore, dimensions, etc.
[4] Grades of 36 to 44 pct manganese contain 60 pct manganese plus iron. Grades of 30 to 40 pct manganese contain 5 to 10 pct iron.
[5] Below current mining grades.
[6] Total 473 million tons; allocated to the Mamatwan Mine (433 million tons) and the Middleplaats Mine (40 million tons).
[7] Bishop, Gloucester, Paling Mines, shut down.
Source: Adapted from reference 16.

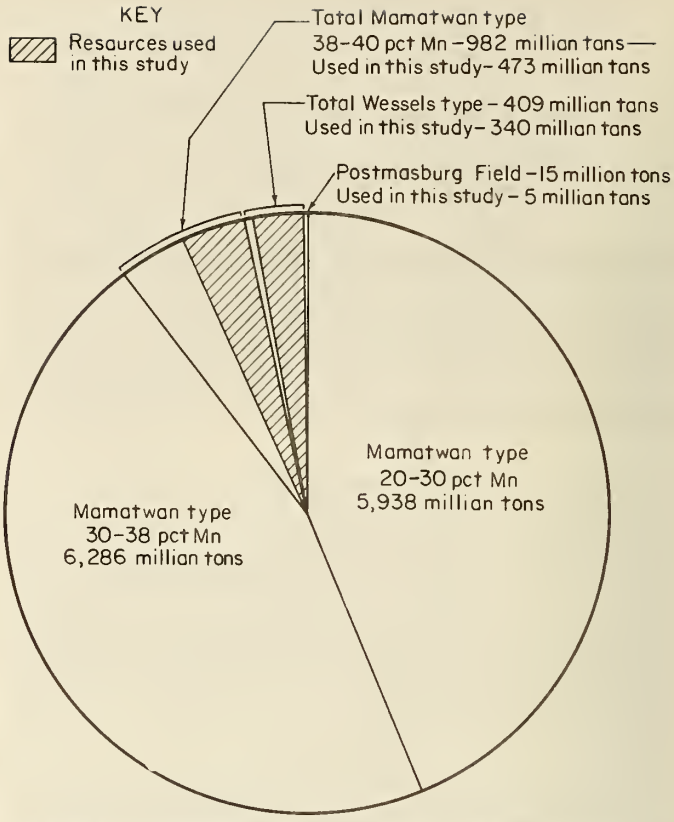
KEY
Resources used in this study
Total Mamatwan type
38-40 pct Mn - 982 million tons
Used in this study - 473 million tons
Total Wessels type - 409 million tons
Used in this study - 340 million tons
Postmasburg Field - 15 million tons
Used in this study - 5 million tons
Mamatwan type
20-30 pct Mn
5,938 million tons
Mamatwan type
30-38 pct Mn
6,286 million tons

Figure 5.—Manganese ore resources of South Africa by grade.

this is considered a result of grade fluctuation within the ore body and is not part of a lower grade resource category. Additionally, the grade ranges below those used in this study (30 to 38 pct and 20 to 30 pct manganese) are too broad to attempt economic analysis on specific grades.

In addition to these Northern Cape deposits, a relatively small tonnage occurs in a number of small deposits in the Gopane area (Transvaal), which is mined for the chemical-grade ore for use in uranium purification (*8*). Because of its small size and the nonmetallurgical use of the ore, this area was not included in the study.

Undoubtedly, South Africa will be a major supplier of manganese for many years. Because of the lateral continuity of the ore beds in and around the major mines, a high degree of mechanization is possible.

The potential for increasing production in South Africa is favorable. In the major mines, significant increases could apparently be accomplished in a short time by adding more production shifts (*6*, p. 113).

For this study, it is assumed that 65 pct of the ores and concentrates produced in South Africa are exported through Port Elizabeth (an average rail distance of about 1,250 km), and the remaining 35 pct is used in the ferromanganese smelters in Transvaal (an average rail distance of about 900 km).

Operations

All operations in the Kalahari and Postmasburg Fields are controlled by two companies, The Associated Manganese Mines of South Africa Ltd. (AMMOSAL), which operates the Black Rock area mines, and South African Manganese Amcor, Ltd. (SAMANCOR), which operates the Mamatwan, Middleplaats, Wessels, and Lohathla Mines.

Kalahari Field

The Kalahari Field contains a relatively continuous belt of manganese ore that extends about 40 km in a north-south direction. This field contains nearly all the significant manganese ore resources of South Africa. The ore in this field is laterally consistent and can be mined by mechanized methods.

There are two separate grade classifications within the Kalahari Field—the higher grade, high-iron Wessels type in the northern part of the field and the lower grade,

low-iron Mamatwan type in the southern part of the field. The largest resources are of the Mamatwan type. Mamatwan-type ore contains calcareous impurities which somewhat restrict its use in electric furnace manganese ferroalloy production and is generally blended with high-grade ores such as the Wessels type.

Black Rock Area

The Black Rock area is in the northern part of the Kalahari Field and currently includes three mines owned and operated as a unit by AMMOSAL, the Gloria, Nchwaning, and Nchwaning West. Total annual output from the three mines is about 2 million tons. Resources are estimated at 132 million tons in the plus 44 and 40 to 44 pct Wessels-type ore.

These mines are located on adjacent farms and are operated at varying rates depending on ore contract specifications. Grades vary between the mines, and certain sections are mined as the need arises to maintain an overall consistent grade product.

The broad structure of the ore-bearing banded iron formation in this area is a north-trending asymmetrical anticline planed off by faulting. The strike length of the ore body is about 10 km. Two persistent ore bodies are developed, each of which is approximately 6 m thick with consistent thickness and grade down dip. The area being mined at Nchwaning is the bottom ore body of the eastern limb of the anticline. The depth of the cover ranges from 150 to 900 m. The major ore minerals are braunite, bixbyite, and cryptomelane, with calcium and magnesium carbonates.

The main ore bodies at the Gloria and Nchwaning West are also on the eastern limb of the anticline. The ore horizons here range in thickness from 5 to 40 m and dip from 0° to 30°.

Mining in the Black Rock area is underground, using basically a room-and-pillar method; selective mining is used in some areas of the mine to produce higher grades. The ore body is accessed by one vertical and one inclined shaft to a depth of 400 m.

The waste is sorted from the ore manually before it is crushed, screened, and washed. Some final sorting to various grades and specifications is done by visual identification. Four different grades of manganese concentrates are produced.

Mamatwan Mine

The Mamatwan Mine is located at the southern limit of the Kalahari Manganese Field and is owned and operated by SAMANCOR. The manganese deposit varies in thickness from the suboutcropping to an average of 45 m. At the base, the ore is siliceous and ferruginized with a banded appearance. The manganese ore is normally overlain by banded ironstone, which thickens to 15 m within the lease area. Except for occasional fissures, the manganese ore body is not affected by faulting and folding.

The ore body consists of approximately 48 pct braunite, 14 pct manganite, 22 pct calcite, 5 pct magnesite, 6 pct hematite, and other minor minerals. The resources used for the study are estimated at 433 million tons. This includes only the grades of 38 to 40 pct manganese, and roughly coincides with the strike length of 4 km explored by 300 drill holes on the Mamatwan and Goold properties (*16*, p. 8); one stated reserve is over 200 years' production (*15*, p. 193).

Mining is proceeding to the north along the strike of the ore zone and is performed by conventional open pit mining methods utilizing drilling machines, large power shovels, front-end loaders, and dump trucks. Current annual capacity is about 2.2 million tons. Currently, the manganese ore being mined is about 40 m thick and is covered by about 50 m of overburden, including about 7 m of sand. The sand is removed by a bucket-wheel excavator, and the hard rock overburden (limestone and banded ironstone) is blasted and removed in three benches. The ore is also excavated in a series of three benches.

In 1981, an in-pit crusher and conveyor system were installed so that the crushed ore can now be transported about 2.2 km to the secondary crushers and wet-screening plant by conveyor. The conveyor system was designed for twice the capacity of the in-pit crusher for the possibility of increasing capacity by adding another crusher.

At the secondary crusher and screening plant, the ore is crushed to minus 75 mm and wet-screened into plus 25-mm, minus 25- plus 6-mm, and minus 6-mm sizes. The minus 6-mm fines must be sintered before being used as ferromanganese smelter feed.

Middleplaats Mine

The Middleplaats Mine was purchased from the Anglo American Corp, by SAMANCOR in March 1982. At the Middleplaats, the ore horizon lies at a vertical depth of 300 to 500 m below the surface. The deposit is stratabound and dips 10° to the northwest. The ore is generally hard and competent and normally occurs as a mixture of manganese silicates and oxides. The thickness ranges from 8 to 14 m. The principal gangue minerals are calcium and magnesium carbonates.

Demonstrated resources for this mine are estimated at 40 million tons in the Mamatwan-grade category of 38 to 40 pct manganese. The mine has a capacity of about 1.2 million tons per year.

The mine is developed by shaft and service ramp. The shaft is 489 m deep, and the ramp is 2,500 m long with a slope of 10° to 12°. The main level is on the footwall at a depth of 400 m. The shaft is equipped with a Koepe hoist and is used for ore production and downcast ventilation, whereas the ramp is used for the transport of personnel and equipment.

Mining is by room-and-pillar, where an initial 4-m cut is made on the hanging wall, followed by benching of the lower section. The ore is crushed to minus 150 mm underground before hoisting.

The concentrator consists of secondary crushing, wet screening, and cycloning. The ore is crushed to minus 75 mm and screened into products of minus 75 plus 6 mm and minus 6 plus 2 mm. The minus 2-mm fraction is further processed by cyclones into plus and minus 150-μm fractions. The plus 150-μm product is stockpiled as a potential product, and the minus 150-μm size is considered waste.

Wessels Mine

Wessels ore occurs at a depth of about 300 m in the northern part of the Kalahari Field. On the average, the material contains 44 pct manganese, with braunite, bixbyite, and cryptomelane as the major minerals. Demonstrated resources are estimated at 208 million tons.

The mine began production in 1973 and was designed to replace the production of Wessels-type ore from the Hotazel Mine, which was nearing depletion. Access

initially was by a vertical shaft to a depth of 395 m and an incline of about 1,200 m. A second incline was driven in 1980 and is currently being used for ore haulage to the surface through a cable conveyor belt system. Current mine capacity is about 1.5 million tons per year.

Mining is by conventional room-and-pillar methods, although limited selective mining is done for grade control. This is because of a vertical gradient in the manganese content with the upper approximate 0.6 m of ore being of lower grade. Here the upper section is excavated first and stockpiled separately, and then the lower approximate 4.5-m section is mined. The mine is not adaptable to such large-scale equipment as the Middleplaats Mine, since the ore horizon is thinner (about 5 m) and there are a number of small-scale faults and changes in dip.

Crushing is done underground with satellite primary crushers located at the main haulageway intersections and a secondary crusher located at the belt loading station. The satellite crushers reduce the ore to minus 125 mm; this product is further reduced to minus 63 mm for transport to the surface.

The surface plant is a secondary crushing and wet-screening plant that produces product sizes of plus 32, minus 32 plus 6, and minus 6 plus 1 mm. The rock smelted in South Africa is blended with Mamatwan-type ore for use in company ferromanganese plants.

Postmasburg Field

The ore in the Postmasburg Field occurs as a broken series of remnants lying about 1,800 m stratigraphically below the Kalahari Field and is divided into eastern and western belts. The eastern belt contains higher grade siliceous ores occurring in tectonic siliceous breccias along or close to their contact with a dolomite. The western belt contains lower grade ferruginous ores. These manganese deposits are marked by intricate shapes and inconsistent sizes.

The only mine operating in the Postmasburg Field is the Lohathla Mine owned by SAMANCOR. Until recently, three other mines, Bishop, Gloucester, and Paling, owned by AMMOSAL, were producing a total of about 300,000 tons per year. These mines are now shut down, and there is little likelihood they will reopen because of the high cost of mining (labor intensive), low reserves (about 10 million tons), and low-grade product (28 to 33 pct manganese).

At the Lohathla Mine, one of the main resources of manganese is siliceous detrital ore. The detrital ore has been formed at the foot of the elevated ground owing to erosion. Resources are estimated at 5 million tons; however, the manganese ore bodies are so irregularly shaped that resource estimations are very difficult.

Run-of-mine ore is transported by 17-ton trucks to the processing plant located adjacent to the mine. Waste materials in the run-of-mine ores are hand sorted on sorting belts before the ore is crushed, washed, and screened. The processing plant produces up to six different grades of contained manganese in concentrates.

Ferroalloy Smelters

South Africa has four ferromanganese smelting plants with an annual ferromanganese capacity of 563,000 tons and a silicomanganese capacity of 122,000 tons. These plants are shown below (*6*, p. 117; *11*, p. 157):

Smelter	Annual capacity, thousand tons		Location
	FeMn	SiMn	
Meyerton	393	52	50 km south of Johannesburg.
Witbank	10	70	100 km northeast of Johannesburg.
Cato Ridge	100	NAp	Near Durban, Natal.
New Castle	60	NAp	About midway between Johannesburg and Durban.
Total	563	122	

NA—Not applicable.

Each of these smelters is located a considerable distance from the manganese mines (Meyerton—750 km, Witbank—900 km, Cato Ridge—1,450 km, and New Castle—1,000 km). The average distance from the mines to the various smelters is estimated to be 800 to 900 km. The average rail distance for exporting the ferromanganese is 1,450 km, while the rail distance for transporting the concentrates to Port Elizabeth for export is about 1,250 km.

UNITED STATES

Certain manganese resources of the United States were evaluated in a previous study (*10*). Eight deposits were evaluated and estimated to contain nearly 422 million tons of material containing an average of about 10 pct manganese. As shown in table 4, these deposits contain very low grades not approaching the grades of manganese ore in the 23 foreign mines and deposits evaluated for this study.

Recent significant factors in the U.S. manganese industry are a decrease in production of ferromanganese and a corresponding increase in imports. In addition, nearly all U.S. manganese ferroalloy plants have been acquired by foreign companies, some of which are current ore producers. Trends in U.S. imports of manganese ore and ferromanganese production for 1970 to 1981 are shown in figure 6. As indicated in figure 6, there has been a marked decrease in ore imports and ferromanganese production in these years and an increase in ferroman-

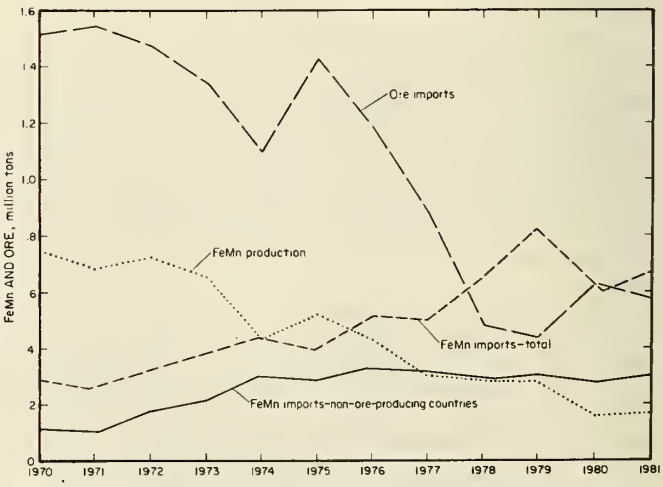

Figure 6.—U.S. ferromanganese production and imports and mangenese ore imports, 1970 to 1981.

ganese imports. Of significance also is the increase in ferromanganese imports from non-ore-producing countries. On the other hand, in 1973–78, when comparative data are available, ferromanganese imports of non-ore-producing countries other than the United States remained relatively stable (*9*, p. 49). Apparently the United States has absorbed much of the new ferromanganese production from the ore-producing countries.

Although nearly all ferromanganese smelters are shut down, the U.S. annual smelting capacity (either producing or shut down on a care and maintenance basis) is estimated to range between 250,000 and 350,000 tons for high-carbon ferromanganese and was estimated at approximately 250,000 tons for silicomanganese as of January 1983. The range of the high-carbon capacity is because of the uncertainty as to whether or not the plants shut down on care and maintenance would reopen with improvement of market conditions.

UPPER VOLTA

The Tambo manganese deposit is located in a relatively remote region of Upper Volta. It occurs in two adjacent hills about 150 m apart and lies about 100 m above the general level of the surrounding terrain. The manganese occurs in three separate structures which are of a slightly different average manganese content, classified as first, second, and main manganese oxide zones. The main oxide zone is the highest grade material and contains material of up to 55 pct manganese (*13*).

The Tambao oxides are variable in character. They can be layered or bedded, solid or massive, concretionary or cavernous, rubbly or friable. Generally, the central parts of the ore bodies are of the massive, black-grade oxide type, but towards the margins of the ore zones these pass into a slabby softer ore containing thin beds of argillaceous matter and kaolins. Resources are estimated at 16 million tons containing about 54 pct manganese (*20*, p. 202).

Development of this deposit would require the construction of about a 350-km railroad and a total rail haulage distance of about 1,500 km. High development and concentrate transportation costs, in addition to problems between the Ivory Coast and Upper Volta Governments regarding the railroad transport system and terms for the use of the port, have inhibited the development of this deposit.

ALTERNATE SOURCES OF SUPPLY

Probably the only long-term manganese supply that could be exploited by the United States at some future time is contained in sea nodules. The National Defense Stockpile could be used for a short-term supply. Steelmaking slags have also been mentioned as an alternative source, but there is no commercial developed technology for the recovery of the manganese contained in slags.

SEA NODULES

Manganese nodules are widespread on the sea floor, particularly in the deeper sections. The composition of these nodules ranges from 1.8 pct to nearly 34 pct manganese. In nearly all cases, the manganese is associated with appreciable amounts of other valuable metals including cobalt, nickel, copper, and molybdenum. Although manganese comprises the major metallic constituent, cobalt, nickel, and copper constitute the primary metals of economic importance.

In the most promising area of the Pacific Ocean southwest of the Hawaiian Islands between latitude N 8°30′ and N 10°00′, and between longitude W 131° and W 150°, the average concentration of nodules is estimated at 9.76 kg/m³ grading 25 pct manganese, 1.28 pct nickel, 1.16 pct copper, and 0.23 pct cobalt. Within the area, the total quantity of potentially recoverable metals is estimated, using 20-pct mining efficiency, at—

	Million tons
Manganese	500.0
Nickel	23.6
Copper	20.0
Cobalt	4.2

The technology necessary for mining and processing sea nodules has been under research and development for over 10 years. The major problems associated with mining are those connected with the raising of the manganese nodules from the seabed to a surface vessel. A number of processes for the extraction of the metals from the nodules have been examined including chemical, electrochemical, and pyrometallurgical. The most applicable process has not yet been established.

STOCKPILE

The National Defense Stockpile is a Government inventory system to meet essential military defense and civilian requirements in an emergency situation. It is not designed to control market prices or remedy short-term supply disruptions.

A 1978 study (*20*) indicated that private inventories normally hold an estimated 10-month consumption supply, and the National Defense Stockpile carries an estimated 17-month inventory at normal U.S. consumption rates.

At yearend 1981, private inventories carried about 940,000 tons of all types of manganese ore, and the Government stockpile contained about 2.5 million tons of stockpile-grade metallurgical ore and about 870,000 tons of non-stockpile-grade metallurgical ore (*19*, 1981, pp. 573-575). Based on the 1981 consumption rate of about 1 million tons, these inventories, not including the non-stockpile-grade ore, would last about 3 years.

ENGINEERING AND ECONOMIC ANALYSES

To determine the potential availability of manganese, engineering analyses of individual deposits were performed to determine the capital investment and operating cost per ton of marketable product produced. When available, actual data were used in the analysis. For any missing cost data, the computerized cost estimating system (CES), developed by the Bureau of Mines, was used to analyze the engineering parameters of the deposit. To standardize the evaluation, a 1981 U.S. dollar base was used in all cost analyses. Foreign costs were updated to the base year by applying cost indexes. Translation to U.S. dollars was made by applying the U.S. exchange rate to the appropriate country. All costs are assumed to represent the average costs for exploitation of the entire demonstrated resource and thus will not represent current costs.

Mine capital investments were estimated for acquisition, exploration mine development, and infrastructure. Included in the mine capital expenditures were the costs for mobile equipment, plant machinery, the engineering and construction management fee, and infrastructure facilities. Mill capital investments include all mill and beneficiation equipment and machinery, and also the engineering and construction management fee. Working capital was calculated as equal to 60 days of operating and administrative costs. Costs for environmental factors were not considered in the analyses.

Total operating cost was computed as the total of direct and indirect costs of production. Direct operating cost includes operation and maintenance labor and supplies, supervision, payroll overhead, and utilities. Indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities, and research.

Transportation costs were estimated for individual mine outputs. These estimates were based on interpretations of costs of the various modes and distances of transport and an assumption of what appeared to be the most probable destinations of the concentrates considering existing smelting areas.

An important cost factor in mining and milling of manganese ore is for support of the facilities in remote areas where the mines are located. Virtually all the mines are located in remote areas, most of them extremely remote. Support facilities include such things as housing, employee training, medical facilities, schools, recreation, power, access transportation, etc. Even in South Africa where the mining areas were populated before mining commenced, there are no facilities to support an industrial operation such as mining, so these must be provided. In other areas such as Serra do Navio, Brazil, Groote Eylandt, Australia, and Moanda, Gabon, the operations are extremely remote and all services must be provided. These areas would also experience problems in the supply of materials and a very high personnel turnover.

MINING

Terrestrial manganese deposits are mined by either open pit or underground methods. The physical character of the ore body and maximum economic return influence the selection of the specific mining system for any deposit. Although surface mining is generally economically more advantageous than underground mining, underground operations are used when overburden stripping has reached the economic limit and where deposits are deep seated. The continuous character of the ore horizons in the major manganese resource areas permits highly mechanized operations in both open pit and underground mines. Room and pillar is the most widely used underground method.

Of the mechanized operating mines evaluated in this study, eight are open pit and seven are underground. The Molango-Tetzintla Mine in Mexico has separate open pit and underground operations. In terms of both production capacity and demonstrated resource, the open pit mines account for about 60 pct of the total quantities.

The mining operations in India are virtually all labor-intensive hand operations. In some cases a minor amount of mechanization is used, such as a bulldozer or shovel for removing overburden. In India, mining always begins with the excavation of ore on the outcrop; if the horizon is continuous and excessive overburden is encountered, mining is shifted to underground.

In terms of both production and resources, the mechanized mines evaluated in this study account for nearly all of the total quantities.

Mining costs estimated in this study range from about \$6 to \$14 per ton of ore in the mechanized operations. Costs for the mechanized underground mining operations are estimated to range between \$10 and \$14 per ton. Open pit operating costs are estimated to range from \$6 to \$9 per ton. In the nonmechanized operations such as in India, where productivity may be as low at 0.1 ton per worker-shift, mining costs are estimated to reach \$20 to \$25 per ton.

All underground mines, except the Middleplaats Mine in South Africa, are mining higher grade ore (plus 44 pct manganese). The higher costs for the underground mines are compensated for in part by the high grade of ore, by the high degree of mechanization (Middleplaats), and by the ore characteristics as to being able to fit into the smelting complex, such as blending for special constituents, physical characteristics, etc.

BENEFICIATION

All manganese ores must be crushed and screened, and if the ore contains appreciable quantities of low-grade or barren clayey material, then washing is practiced. The adaptability of a particular beneficiation process depends upon the mineralogical character of the ore and the economics of the operation. In general, crushing, screening, and washing may upgrade the product by only 1 to 3 pct manganese. Washing can improve the product more if there is a significant content of lower grade clayey material, such as in the Groote Eylandt Mine in Australia. In most cases, however, the fines removed by washing contain relatively high values of manganese (approximately 20 to 30 pct manganese), and thus the recoveries are relatively low. Recoveries estimated for the operations in this study range from about 60 to 75 pct. Long-term recoveries are difficult to assess, however, because some of the material discarded at one time may be sold as low-grade blast furnace feed later, depending on demand.

Heavy-media separation can be used where there is a significant quantity of silica and alumina gangue in the ore and in some cases for upgrading chemical- and battery-grade ore. This process is currently in use at the Groote Eylandt Mine, the Molango-Tetzintla Mine in Mexico where silica gangue is encountered, and the Serra do Navio operations in Brazil in conjunction with reduction roasting and magnetic separation.

Pelletizing of manganese fines (about minus 1.5 mm) in conjunction with heavy-media separation and spiraling is done by Serra do Navio Mines of Brazil. The final process is a reducing roast to convert hematitic gangue to magnetite. The magnetic fraction is removed, and the remainder of the material is pelletized.

The nodulizing process is normally used in upgrading manganese carbonate ores. The process involves calcining the crushed ore in a rotary kiln to liberate carbon dioxide and to form nodules. Carbon dioxide is first liberated; then further heating softens the ore and forms sized nodules of about 25 mm. At the Molango Mine in Mexico the ore is nodulized and the Nsuta Mine of Ghana installed a nodulizing plant to upgrade the carbonate ores from 31 to about 44 pct manganese (*23*).

In all processes, a certain amount of fines are produced which may or may not be further upgraded or shipped direct as sinter feed. All fines (generally minus 6 mm) must be sintered, and this is done at the smelter installation.

Recoveries of manganese in the processing operations are generally relatively low, ranging from about 60 to 75 pct. The losses are the result of the fine material generated by the process not being adaptable to further processing. This may be the result either of dilution with clayey gangue or of fineness of the material produced in crushing and screening (generally less than 150 μm). The weighted average grade of all concentrates produced from the mines in this study is about 44 pct manganese.

Beneficiation costs for crushing, screening, and washing are relatively standard, about $1 to $2 per ton of feed. Where the ore is processed by simple crushing and screening, the costs would be in the lower part of this range. Washing would increase the costs by a relatively small amount. The higher range of the costs would be experienced in operations where other methods were used, such as heavy-media. Even heavy-media costs are not very significant, because generally only a small part of the feed passes through the heavy-media process.

Of more importance in the beneficiation costs is the treatment of fines produced in the process. These fines are generally in the range of minus 5 to 6 mm plus 150 μm and must be sintered before being adaptable to the production of ferromanganese. It is estimated that the amount of fines produced in the operations evaluated in this study ranges from about 25 to 50 pct. The costs of sintering these fines are estimated to range between about $12 and $16 per ton. These costs are prorated to the mill costs on an individual basis, depending on the amount of fines estimated for each operation.

Nodulizing is done at two operations—Molango, Mexico, and Nsuta, Ghana; the incurred costs are mainly in fuel consumption. Assuming a heating requirement of 3.5 to 4.0 million Btu per ton and 1,000 Btu per cubic foot of gas, the fuel requirement wuld be about 3,500 to 4,000 ft^3 per ton of product. The advantage of this process is that the manganese content of the carbonate ore can be increased by 12 to 15 pct with little recovery loss.

TRANSPORTATION

Transportation is by far the most significant cost element in the production of manganese concentrates since nearly all the ore must be transported long distances to smelters. Even land transportation distances to smelters within the ore-producing countries are not significantly different from the distances required for export. Since there is virtually no possibility of development of manganese resources nearer to the major market areas, transportation will continue to be the major cost factor.

A comparison of land transportation distances for export and in-country use is shown in table 6.

Costs for land transportation by truck can vary greatly depending on road conditions and the type of haulage equipment used. For this study, data indicated that costs range from about $0.06 to $0.20 per ton-kilometer. Truck transportation costs are relatively insignificant in total world manganese production, howev-

Table 6.—Manganese land transportation distances and modes

Country and mine	Exported		Percent exported	Domestic use: Distance (km) and mode
	Distance (km) and mode	Destination		
Australia Groote Eylandt	16—truck	Milner Bay	75	16—truck.
Brazil				
Santana	NAp	NAp	0	30—truck.
Serra do Navio	200—rail	Santana	100	NAp.
Urucum	30—truck	Corumba	50	1,500—rail.
	2,700—barge	Nueva Palmira, Uruguay		
Azu-Buritarama-Sereno	930—rail	Sao Luis	50	930—rail.
Gabon Moanda	76—ropeway	Railhead	100	NAp.
	485—rail	Pointe Noire, Congo		
Ghana Nsuta	60—rail	Takoradi	100	NAp.
India				
Central Balaghat Kandri, Munsar Tirodi Ukwa	450—rail	Visakhapatnam and Bombay	50	50—rail.
Karnataka (Bisgod Mine)	140—truck	Beligondi	70	50—truck.
Keonjhar District	350—rail	Visakhapatnam and Bombay	50	400—rail.
Mexico Tetzintla	230—truck	Tampico	50	230—truck.
South Africa				
Kalahari Field	1,250—rail	Port Elizabeth	65	900—rail.
Postmasburg Field	1,150—rail	do	65	800—rail.
Upper Volta Tambao	1,500—rail[1]	Abidjam, Ivory Coast	100	NAp

NAp Not applicable
[1] Proposed explored deposits

Table 7.—Estimated manganese ore and concentrate ocean shipping rates
(Dollars per ton)

Originating country and port	Destination		
	United States	Europe	Japan
Australia:			
Milner Bay	30	30	12
Brazil:			
Santana	12	16	26
Rio de Janeiro	18	22	30
India:			
Visakhapatnam	36	30	18
Bombay	32	26	22
Mexico: Tampico	10	17	24
Gabon:			
Pointe Noire, Congo	28	28	34
Ghana: Takoradi	23	21	28
South Africa:			
Port Elizabeth	30	30	32
Upper Volta:			
Ivory Coast	23	21	28

er, since they are involved in only a small number of mines.

Rail haulage involves long distances in nearly all manganese operations. A number of factors can influence the costs of rail haulage, such as size of the cars, condition and availability of the track, use of multiple units (unit trains), or Government policies such as special taxes, tariffs, or rebates. For this study, rail haulage rates are estimated to range between about $0.020 and $0.035 per ton-kilometer.

Ocean transportation is generally the highest cost element in the transportation of manganese concentrates to main market areas. Estimated ocean shipping rates from loading ports to the various use areas are shown in table 7.

Cost data for ocean transportation are generally very difficult to obtain and can be unrepresentative when applied to specific cases. This is because rates can vary drastically, depending on the availability of ships. Also, different ports have different loading facilities that can affect costs. In addition, destinations of the concentrates can be extremely variable, generally on an annual basis, depending on contracts between buyers and sellers. Other variables in ocean shipping costs include the capacity of the ships, or whether or not the ships are under term contract or are owned by either the buyer or the producer. In some cases, prices for shipping are negotiated for each load.

SMELTING

Smelting of manganese ore for the production of ferromanganese is carried out in either a blast furnace or a submerged arc electric furnace.

Blast furnace smelting can utilize iron blast furnaces converted to ferromanganese smelting. When this is the case, the primary use of the smelter is to supply the steel complex in which it is located. Excess production could be sold on the open market. An exception is the Boulogne blast furnace smelter in France, which was constructed for the purpose of supplying ferromanganese to the open market. The majority of ferromanganese sold on the open market, however, is produced in electric smelters. Any new smelters built will undoubtedly be electric furnaces.

Electric furnaces can be used for producing all forms of manganese ferroalloy and other ferroalloys as well, whereas the blast furnace can only produce high-carbon ferromanganese. Recoveries in the electric furnace are higher when the slags, which may contain 30 to 35 pct manganese, are used to produce silicomanganese which may be used as is or can be used to produce medium- and low-carbon ferromanganese. The production of silicomanganese in the electric furnace process from these slags is mandatory, if the manganese in the slags is to be recovered. The slag is upgraded by the addition of manganese ore and resmelted to produce the silicomanganese.

It is estimated that manganese recoveries to final products in the electric furnace would be about 95 pct and in the blast furnace about 80 to 85 pct (*9*, p. 63). If the slag in the electric furnace process were not used for silicomanganese production, electric furnace recoveries would be about the same as those for the blast furnace.

A variable type and quality of manganese ores and concentrates is used in ferroalloy smelting, depending on the availability of specific types of ores and the desired quality and type of ferroalloy produced. For this reason, complex blending of the ores for ferromanganese smelter feed is done at all smelters. The blending will nearly always include ores from four or five different sources. Blending is not entirely contingent upon manganese content but may be used to control the quantity of other constituents such as iron, silica, phosphorus, alumina, alkalies, and manganese and calcium oxides. In South Africa, a mixture of the high-grade, high-iron Wessels ore is blended with the relatively low grade, low-iron Mamatwan ore to obtain a higher manganese-to-iron ratio (*15*, p. 19). The nodules produced from the Molango ore in Mexico must also be blended with a higher grade ore to produce a market-grade ferromanganese, and the ores in the Urucum area in Brazil must be blended to dilute the high alkali content.

It is estimated that the ore-producing countries have the manganese ferroalloy production capacity to utilize about 26 pct of their ore production capacities estimated in this study, based on an average usage of about 2.2 tons of ore per ton of ferromanganese and 1.4 tons of ore per ton of silicomanganese produced. Ferroalloy production capacities of the major ore importing and exporting countries are shown in table 8.

The only recent development in the construction of new ferroalloy smelters is the 72,000-ton-per-year plant at Tumsar, India, which was built to utilize the ores of the Madhya Pradesh-Maharashtra area in central India.

In view of the 11.6 million tons of manganese ore production in 1982, there is a substantial overcapacity in smelters at the present time. Assuming 25 pct of the ore (approximately 35 pct manganese) is used as blast furnace feed, and about 500,000 tons is used for the battery and chemical industry, the effective ore production designated for ferromanganese smelter feed would be about 9.1 million tons, or about 76 pct of the smelting capacity.

Using the factors of 2.2 and 1.4 tons of concentrate per ton of ferromanganese and silicomanganese, respectively, about 8.5 million tons of concentrate would be used in 1982. This would leave a concentrate surplus of about 400,000 tons, even though only about 76 pct of the smelting capacity was being used.

The smelting overcapacity has caused a shutdown of a number of smelters in the ore-importing countries. As an example, the United States had only 1 ferromanganese smelter operating as of January 1983 out of 11 available.

Table 8.—Annual manganese ferroalloy capacities and ore requirements of major ore importing and exporting countries
(Tons)

	Ferromanganese		Silicomanganese		
	Capacity	Ore requirement	Capacity	Ore requirement	Total ore requirement
ORE-IMPORTING COUNTRIES OR AREAS					
Canada	90,000	198,000	50,000	70,000	268,000
Western Europe	1,908,000	4,198,000	427,000	598,000	4,796,000
Japan	727,000	1,542,000	575,000	805,000	2,347,000
United States	[1]350,000	770,000	240,000	336,000	1,106,000
Total	3,049,000	6,709,000	1,292,000	1,809,000	8,517,000
ORE-EXPORTING COUNTRIES					
Australia	115,000	253,000	25,000	35,000	288,000
Brazil	140,000	308,000	180,000	252,000	560,000
India	307,000	675,000	56,000	78,000	753,000
Mexico	150,000	330,000	50,000	70,000	400,000
South Africa	563,000	1,239,000	122,000	171,000	1,410,000
Total	1,275,000	2,805,000	433,000	606,000	3,411,000
Grant total	4,324,000	9,513,000	1,725,000	2,415,000	11,928,000

[1] Assumed maximum.

It is possible that in the event of future increases in ferromanganese demand, the ore-producing countries will attempt to expand their existing smelting facilities to meet the demand.

A smelter operating cost is assumed for the deposits evaluated in this study to illustrate the effect of the cost components of mining, beneficiation, transportation, and smelting on the total production costs. For this purpose, it is assumed that average operating cost for a smelter would be about $117 per ton of concentrate in all countries except South Africa and India. In South Africa, smelting costs are assumed to be about 8 pct lower, or about $108 per ton of concentrate. This is because the main smelting installation (Meyerton) is relatively modern and efficient. In India, because of the lower degree of mechanization, smelting costs are assumed at $135 per ton of concentrate.

In Western Europe and Japan, labor costs are generally lower than in the United States, but it is assumed that this is compensated for by higher power costs.

In Brazil, the smelters in the Corumba area have low powers costs; however, these plants are relatively remote, and supplies and the ferromanganese product must be transported relatively great distances. In addition, most of the plants in Brazil are small and therefore would not have cost economies of scale.

The concentrates in Mexico (about 39 pct manganese) must be blended with imported high-grade concentrate to make a marketable alloy, and in Australia high labor rates could compensate for the low power rates.

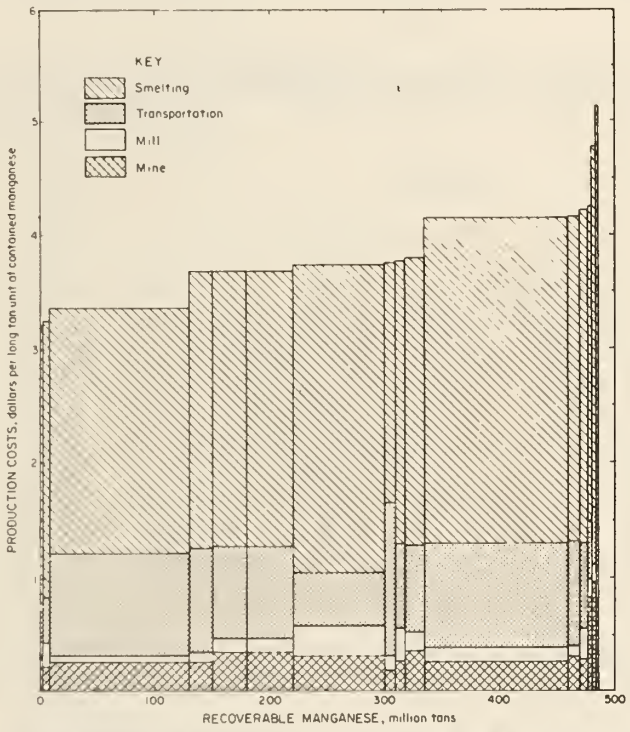

Figure 7.—Market economy country manganese production costs.

PRODUCTION COST SUMMARY

Comparative operating costs to produce manganese ore and concentrates and ferromanganese are illustrated in figure 7. All costs are direct operating costs in terms of dollars per long ton unit of contained manganese in ore and therefore represent the effect of manganese grade on the cost elements. Additionally, the costs are based on mining and beneficiation of the entire resource and do not include taxes, insurance, brokerage fees, warehousing, etc., or profit or rate of return on investments. Transportation and smelting costs that are assigned to particular mines and deposits are based on assumed delivery patterns to areas of smelting.

As shown in figure 7, estimated mine operating costs range from about $0.20 to $0.34 per unit, and beneficiation costs range from about $0.05 to $0.45 per unit. The major variance in the milling costs represents nodulizing and the amount of sintering required.

Transportation costs show the largest variance of all costs—from about $0.30 to $1 per unit. These costs are dependent on the geographic location of the mines and the modes of transportation to market areas.

The relationships of the cost elements through concentrate production and delivery to the smelting areas and through smelting are shown in figures 8 and 9, respectively.

As previously stated, U.S. dependence on ferroman-

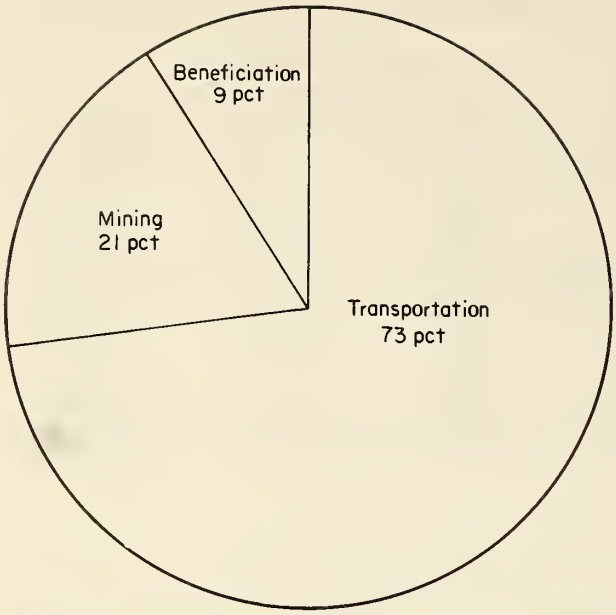

Figure 8.—Relationship of cost elements through manganese ore and concentrate production.

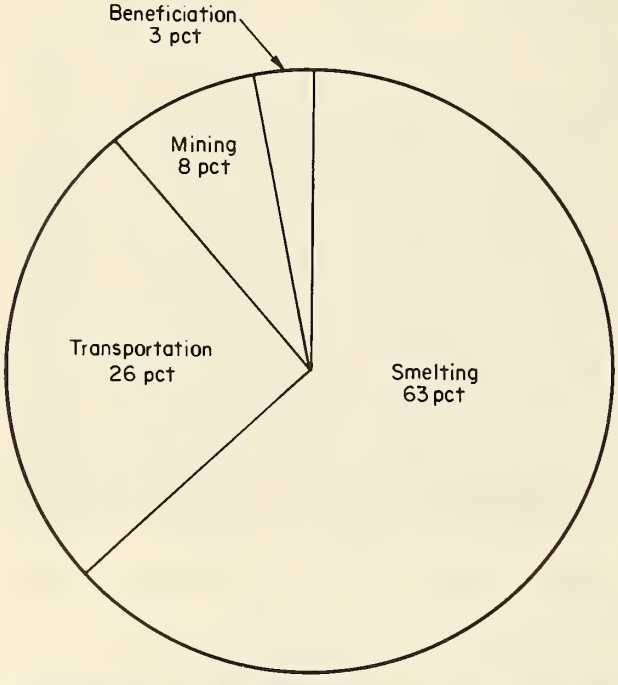

Figure 9.—Relationship of cost elements through ferromanganese production.

ganese from non-U.S. sources has increased in recent years. The increased imports have been not only from ore-producing countries but also from countries that import the ore, smelt it, and ship the ferromanganese to the United States. On a per unit of contained Mn basis, there appears to be more of a transportation cost advantage to shipping the ore to the United States for smelting rather than importing the ferromanganese.

Table 9.—Manganese ore and ferromanganese transportation costs, comparing smelting in South Africa and in the United States

(U.S. dollars)

	Smelting in South Africa		Smelting in the United States	
	Per ton product	Per unit contained Mn	Per ton product	Per unit contained Mn
Mine to smelter (ore)	16.00	0.36	NAp	NAp
Smelter to port (ore)	NAp	NAp	25.00	0.57
Smelter to port (ferromanganese)	34.80	.47	NAp	NAp
Shipment from South Africa to U.S. market:	NAp	NAp	30.00	.68
Ore	36.00	.49	NAp	NAp
Ferromanganese				
Total	NAp	1.32	NAp	1.25

NAp Not applicable.

Using South Africa (the largest ferromanganese supplier to the United States) as an example, and a similar type of ore (estimated 44 pct manganese) and ferromanganese at 74 pct manganese, table 9 shows transportation costs for shipping ore versus ferromanganese to the United States.

The shipping distance for transporting the ore to South Africa smelters was assumed at 800 km; distance for shipping the ore to Port Elizabeth for export was assumed at 1,250 km. To ship the ferromanganese to ports for export, a distance of 1,450 km was assumed. Costs of $0.020 and $0.024 per ton-kilometer were assumed for ore and ferromanganese rail transportation, respectively.

If 51-pct-manganese Gabon ore were used as a comparison, the difference would be greater since the comparable transportation cost would be about $48 per ton of concentrates from the mine, or about $0.94 per unit of manganese ($48/51 units of manganese per ton). Thus the transportation cost advantage of smelting Gabon ore in the United States instead of importing ferromanganese smelted in South Africa from South African ore would be about $1.32 minus $0.94, or about $0.38 per unit.

Table 10 shows comparison of transportation costs involved in ferromanganese smelting in France (the second largest U.S. supplier of ferromanganese) and the United States. For this example, Gabon concentrates (51 pct manganese) are used. The locations of the plants in this example are Boulogne in France and Marietta, Ohio.

As near as can be determined, the ocean shipping rates between the port of origin (Pointe Noire, Congo) and either Boulogne, France, or New Orleans are similar at an estimated $28 per ton. Since Boulogne is a seaport, costs for delivery to the smelter are less than the barging costs from New Orleans to Marietta as shown in table 10. This difference is more than offset by the ferromanganese transportation costs from France to the United States.

Table 10.—Manganese ore and ferromanganese transportation costs, comparing smelting in France and in the United States

(U.S. dollars per long ton unit)

	Smelting in France	Smelting in United States
Ore:		
Transportation to France	0.55	0.55
Delivery to smelter location	.02	.16
Ferromanganese:		
Transportation to the United States	.37	NAp
Delivery to market areas	.16	.07
Total	1.10	.78

NAp Not applicable.

AVAILABILITY OF MARKET ECONOMY COUNTRY MANGANESE

This study analyzed potential manganese production based upon the demonstrated resources of 31 manganese mines and deposits in 9 market economy countries (including the United States); of these resources, an in situ amount of about 2.2 billion tons was represented and provided a total production potential of approximately 514 million tons of contained manganese in concentrates. The economic evaluations of each deposit were performed using discounted cash flow rate of return (DCFROR) techniques.

All economic evaluations were performed using the computerized Supply Analysis Model (SAM) (2). This evaluation determines the cost of the manganese that equates the present value of revenues over the life of the mine to the present value of all costs of production, including a prespecified rate of return on investment. This determined value is equivalent to the long-run total cost of production for the deposit under a set of assumptions and conditions (e.g., mine plan, design capacity production, and a market for all output) that are necessary in order to make an evaluation. This long-run total cost was determined (in January 1981 dollars) at an assumed rate of return of 15 pct over the life of the deposit.

The model contains a separate tax record file for each foreign country and automatically applies and relevant tax information to each deposit under evaluation. In addition, it holds a separate file of economic indexes to permit continuous updating of all cost estimates.

Using January 1981 as the initial year, a cash flow generation of individual preproduction and production years was performed. After the cash flow generation, all properties under study were analyzed and aggregated to estimate manganese availability curves.

The availability of manganese from a deposit is presented in this study as a function of total cost associated with development, mining, concentration, and transportation. The evaluations are based on the utilization of the entire resource of each deposit.

POTENTIAL TOTAL MANGANESE PRODUCTION (CONTAINED IN CONCENTRATE)

The potential production of manganese based on the long-run total cost of each operation is illustrated in figure 10. At a 15-pct DCFROR, the individual deposit costs range from about $1 to $35 per long ton unit of contained manganese in concentrate. These costs are for the delivered material to ferromanganese smelting areas and are estimated to include costs that would be incurred in exploitation of the entire resource of each deposit.

The curve estimates the availability of manganese that is potentially recoverable at certain costs. At up to $1.50 per long ton unit, the total potential recoverable manganese (metal) is about 213 million tons. At up to $1.75, total potential recoverable manganese would be about 428 million tons, and about 491 million tons would be available at up to about $3.25. The analyses were performed in constant January 1981 dollars.

The U.S. total potential recoverable manganese amounts to approximately 23 million tons and is not reflected on the curve. This is because the lowest determined long-run total cost for U.S. manganese resources is about $8 per long ton unit of contained manganese, which is approximately 2½ times greater than the highest cost for any foreign operation. This determined long-run total cost causes all U.S. potentially recoverable manganese to fall beyond the scale of the curve. An analysis of U.S. potential manganese resources is discussed in BuMines IC 8889 (*10*).

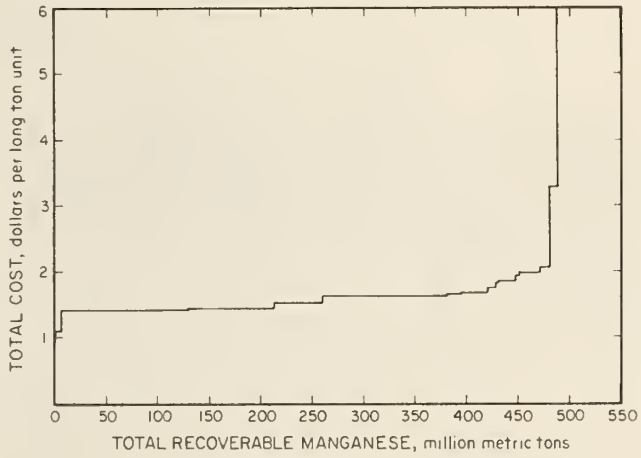

Figure 10.—Cost and total availability of world manganese; cost is in January 1981 dollars and includes a 15-pct DCFROR.

POTENTIAL ANNUAL MANGANESE PRODUCTION

Another method of illustrating manganese availability is to disaggregate the total resource availability curve and show potential production on an annual basis. Figure 11 illustrates the potential annual production of contained manganese in concentrates at various determined long-run total costs from 1981 through 2025. The curves are based on current production capacities for the producing mines and estimated design capacities for the two nonproducing operations. The annual curve does not take into account possible delays caused by environmental, legal, fiscal, financial, market, or other problems.

The figure also illustrates that 75 pct, or approximately 5.8 million tons, of the total potential annual manganese production is available at a cost of $1.75 or less per long ton unit.

These analyses indicate that present potential annual capacity can very well handle the free world market requirements through the year 2025 without any additional capacity expansion, assuming no significant increase in demand over that of the average 1976–82 production rate.

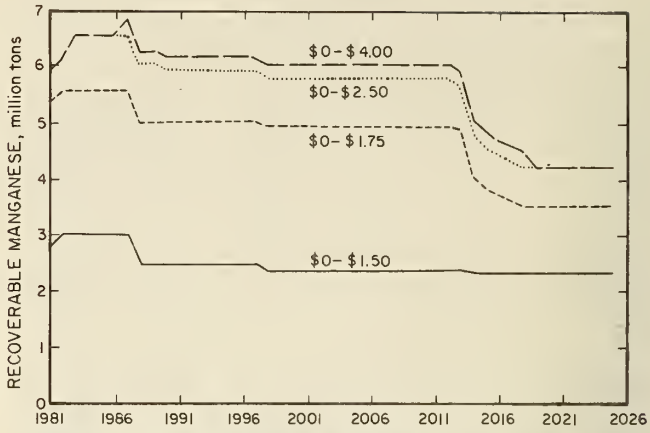

Figure 11.—Cost and annual availability of world manganese; cost is in January 1981 dollars and includes a 15-pct DCFROR.

CONCLUSIONS

The demonstrated in situ resources contained in the 31 mines and deposits analyzed in this study amount to approximately 2.2 billion tons in 9 market economy countries (including the United States). From this demonstrated resource, an estimated 514 million tons of manganese is recoverable. The analyses indicate (given all parameters remain constant as of the initial year, 1981) that at a long-run total cost per deposit of up to $1.75 per long ton unit, over 30 pct of this material (about 413 million tons) is potentially available. Operating mines in Australia, Brazil, Gabon, and South Africa account for approximately 98 pct of the total available at this indicated cost.

Demonstrated resources of manganese are sufficient to serve well into the next century. Based on the average 1976–82 production rate of about 13.7 million tons and assuming between 5 and 6 million tons of manganese content, the demonstrated resources of the current operating mines would last about 80 years. As manganese deposits with tonnage estimates at the identified resource level, such as in Australia, Brazil, Gabon, and South Africa, are further explored, they could be upgraded to demonstrated resources, significantly increasing the future availability of manganese.

On the basis of contained manganese in concentrate, nearly 80 pct of the market economy country demonstrated resource included in this study is contained in seven operating units: Groote Eylandt, Australia; Serra do Navio, Brazil; Moanda, Gabon; and the Black Rock area, Middleplaats, Wessels, and Mamatwan, South Africa.

This study analyzed only the deposits containing material of current mining grade with the exception of the United States. The only foreign area where lower grade resources have been quantified is South Africa. These resources amount to approximately 5.7 billion tons containing 30 to 38 pct manganese and a further 5.1 billion tons containing 20 to 30 pct manganese. Undoubtedly, lower grade resources may also occur in association with other known deposits as well, although apparently very little work has been done to delineate them.

Thus, it appears quite definite that the long-term world supply of manganese will be from the current producing areas. The major consuming areas of the United States, Western Europe, and Japan have no resources that can impact this current supply status.

The most significant cost element in the manganese ore production process is transportation. By far the majority of production is from highly mechanized operations. Concentration of the ore generally involves crushing, screening, and washing, and thus these costs are relatively uniform.

The long-term world situation with regard to manganese supply is principally one of competition between the major producing mines for markets. In that seven operating units, all in a current competitive cost position account for over 400 million tons of recoverable manganese, the long-range manganese supply for approximately the next 80 years is assured.

In recent years, the manganese ferroalloy smelting capacity of the United States has decreased significantly, as is indicated by a change in the relative import quantities of ferroalloys versus ore. This has been caused in part by increases in smelting capacities in the ore-producing countries. By contrast, there has been comparatively little decline in smelter production in Western Europe, which exports ferromanganese to the United States. This is evidenced by the fact that in the period 1973–78, U.S. imports of ferromanganese increased

by over 200 pct, while the imports of other consuming areas (Western Europe and Japan) did not perceptibly increase.

One deterrent to the smelting of manganese concentrates in the United States is that none of the smelters is integrated with the steel companies, such as is the case in Japan, where the ferroalloy could be supplied to the steel plants at cost if necessary.

As of 1983, market conditions in the market economy countries will sustain only about 76 pct of the available smelter capacity. Undoubtedly, some of the shutdown smelters will not reopen even if it is warranted by increased demand because of the inefficiency of the operations. If demand should be projected to exceed the effective smelter capacity in the future, it is expected that the ore-producing countries would attempt to increase their capacities to meet this demand.

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APPENDIX.—MINES AND DEPOSITS INVESTIGATED BUT NOT EVALUATED FOR THIS STUDY

Country and mine or deposit	*Comments*
Argentina: Fallaron Negro	Small resource, production of about 25,000 tons per year as byproduct of a gold-silver mine.
Bolivia: Mutum	Resource has not been established.
India:	
Barbil	Included in Keonjhar District.
Chickla	Small resource.
Gumagon	Do.
Beldongri	Do.
Kuhiuga	Do.
Bicholim-Sirigoa	Principally an iron deposit.
Harbaliem	Do.
Morocco: Imini	All chemical grade, small resource.
South Africa:	
Annex Langdon	Nearly mined out.
Hotazel	Do.
National	Do.
Rand London	All chemical grade, small resource.
Devon	Included in Black Rock area.
Adams	Do.
Mukulu	Do.
Smartt	Resources low grade.
Paling	Resources small, shut down, will not reopen.
Bishop	Do.
Gloucester	Do.

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